KINETICS STUDY ON ANAEROBIC CO-DIGESTION OF WATER HYACINTH WITH POULTRY LITTER

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Abstract

A study on kinetics of anaerobic co-digestion of water hyacinth with poultry litter in different combinations was carried out in 250 ml batch digesters for 60 days retention period. Co-digestion was carried out in mesophilic temperature range of 30 to 37°C with a total solid concentration of 8% in each sample (fermentation slurry). The biogas was collected by the downward displacement of water and was subsequently measured. The observations show that water hyacinth when co-digested with poultry litter improved biogas yield significantly. The experimental data was tested for its fitness with Modified Gompertz equation. 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 using polymath software. The digester fed with 4gm water hyacinth, 18.87gm poultry litter and 77.13gm of water (PW3) produced maximum biogas of 0.39 l/gVS.

Key words: Retention Period, Anaerobic Co-Digestion, Cumulative Biogas Production, Modified Gompertz equation, Kinetic parameters

I. INTRODUCTION

Conventional energy resources are gradually depleting. With increase in demand, most the resource deficient developing nations are not able to cope up with the price hike, hindering their development rate. Rapid industrial growth has resulted in constant harassment of these resources, by the time ill effects due to uncontrolled usage are also being observed in terms of global warming, which is a major issue of concern to the present and future world community. It is estimated that the fossil fuels will be running out by the next few decades therefore, In today's energy demanding life style, need for exploring and exploiting new sources of energy which are renewable as well as eco-friendly is a must (1, 2, 3). To which Biogas technology offers a very attractive and compatible route for utilizing certain categories of biomass, which would help in fulfilling partial energy needs. Anaerobic digestion (AD) is a technology widely used for treatment of organic waste for biogas production. AD that utilizes manure for biogas production is one of the most promising uses of biomass wastes because it provides a source of energy while simultaneously resolving ecological and agrochemical issues (4). The anaerobic fermentation of manure for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge Water hyacinth (*Eichhornia crassipes*) is a fast growing perennial aquatic plant widely distributed throughout the world (5). This tropical plant which belonging to the family Pontedericeae, can cause infestations over large areas of water resources, resulting in series of consequences, including reduction of biodiversity, blockage of rivers and drainage system, depletion of dissolved oxygen, alteration on water chemistry, and involvement in environmental pollution. Attempts towards the use of biological, chemical and mechanical approaches for preventing the spread of, or eradication of water hyacinth have made no substantial impact. On the other hand, much attention has been focused on the potentials and constrains of using water hyacinth as a biomass for biogas production (6). The possibility of converting water hyacinth to biogas established in a number of developing countries, mainly in India (7, 8, 9, 10). Co-digestion is the simultaneous digestion of more than one type of waste in the same unit. Advantages include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing (11).Studies have shown that co-digestion of several substrates, for example, banana and plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield by as much as 60% compared to that obtained from single substrates (12, 13, 14, 15). Results of co-digestion of food waste and dairy manure in a two-phase digestion system conducted at laboratory scale showed that the gas production rate (GPR) of co-digestion was enhanced by 0.8 - 5.5 times as compared to the digestion with dairy manure alone. A wide variety of substrates, animal and plant wastes have been used for biogas production (16). In these studies, the rate of biogas production was found to depend on several factors such as pH, temperature, C:N ratio, retention time, etc. Co-digestion of sewage sludge with agricultural wastes or MSW can improve the methane production of anaerobic digestion processes and has been recently reviewed (17, 18, 19). The co-digestion of cattle manure with MSW has also been shown to enhance methane production. The present study was undertaken to evaluate co-digestion of water hyacinth and poultry litter (20, 21). Batch experiments were carried out for mixture of water Hyacinth with poultry litter in different ratios. The ultimate goal of the study was to pertain and substantiate the ratio between water hyacinth and poultry litter with which maximum biogas yield can be obtained.

II. METHODOLOGY

A. Sample Collection

Water hyacinth used for the study was obtained from a lake at Kengeri Satellite town (Bangalore, Karnataka, India). Overnight, fresh poultry waste was collected from J M J poultry farm (Bangalore, Karnataka).

B. Materials/Instruments

The following materials/instruments were used for the purpose of this research: weighing balance (Systronics), gas chromatography (CHEMITO), pH meter (Systronics), a mercury in glass thermometer (range 0°C to 100°C), Borosilicate desiccators, silica glass crucibles, oven, grinding mill, temperature controlled water bath, water troughs, graduated transparent glass gas collectors, tap water, rubber cork, connecting tubes and biogas burner fabricated locally for checking gas flammability. AR grade sodium hydroxide and acetic acid manufactured by Ranbaxy laboratories were used as procured without further purification.

C. 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°C. 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. A picture of the biomethanation unit is shown in Figure 1.

Fig. 1. Biomethanation unit

D. Solids Analysis

Total solid (TS) and volatile solid (VS) were analyzed for water hyacinth, poultry litter, cow dung and primary sludge according to standard methods. Table 1 gives the solid analysis and pH of poultry litter.

Table 1. Solid analysis and pH data

Digester	pH	% TS	% VS
Poultry waste	7.1	21.20709	83.47188
Water hyacinth	6.4	16.89544	82.84855

E. Fermentation Slurry

Fresh water hyacinth (leaves, stem and root) on collection was chopped to small sizes of about 2cm and allowed to dry up under the sun for a period of 7 days, after which they were dried in an oven at 60°C for 6 hours. This oven-dried water hyacinth was then ground to fine particles using a grinding mill. To study the anaerobic co-digestion of water hyacinth with poultry litter, a series of batch digesters PW1, PW2, PW3 and PW4 were prepared using the ground water hyacinth.

Table 2 gives the composition of digesters. All digesters were given 10 gm of inoculum obtained from an anaerobic primary sludge digester and 0.3 ml of 10% by volume of acetic acid. Digester DWB (8 gm ground water hyacinth + 92 gm water + 10 gm inoculum + 0.3 ml acetic acid) serves as blank for water hyacinth. Biomethanation of these digesters were carried out in duplication with a retention time 60 days in the mesophilic range (30 – 40°C). Cumulative biogas production, slurry temperatures were monitored throughout the period of the study.

Table 2. Composition of digesters

Digester	Water hyacinth	gm	Poultry litter
PW1	2	28.3	69.7
PW2	3	23.58	73.42
PW3	4	18.87	77.13
PW4	5	14.15	80.85

F. Modified Gompertz Equation

The cumulative biogas production data with time for all digester were tested for fitness with Modified Gompertz equation (22). Modified Gompertz equation gives cumulative biogas production from batch digesters assuming that biogas production is a function of bacterial growth. The modified Gompertz equation is given by equation 1.

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

Where

M Cumulative biogas production, l /(gVS) at any time t

R_m Maximum biogas production rate, l /(g VS d)

λ Duration of lag phase, d

t Time at which cumulative methane production

M is calculated, d

The kinetic parameters P, R_m and λ were estimated for each of the digester using POLYMATH software.

III. RESULTS AND DISCUSSION

A. Kinetics of Biogas Production

The cumulative biogas production data with time for all digester are presented in Table 3. Modified Gompertz equation 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, a modified Gompertz equation was fitted to the cumulative biogas production data. Values of parameters obtained are listed in Table 4. The best fit to Gompertz equation is compared with experimental data in Figures 2, 3, 4, 5, 6 and 7.

Table 3. Cumulative biogas production data.

Days	DWB, l/(g VS)	PW1, l/(g VS)	PW2, (l/g VS)	PW3, l/(g VS)	PW4, l/(g VS)
0	0	0	0	0	0
5	0.006	0.015	0.015	0.015	0.005
10	0.011	0.050	0.050	0.025	0.015
15	0.016	0.150	0.120	0.120	0.025
20	0.022	0.240	0.190	0.200	0.050
25	0.035	0.270	0.250	0.270	0.110
30	0.051	0.320	0.300	0.350	0.200
35	0.096	0.330	0.360	0.370	0.270
40	0.170	0.340	0.370	0.390	0.320
45	0.220	0.340	0.370	0.390	0.320
50	0.230	0.340	0.370	0.390	0.320
55	0.235	0.340	0.370	0.390	0.320
60	0.240	0.340	0.370	0.390	0.320

Table 4. Summary of performance of anaerobic digesters

Digester	Biogas Yield[a] l/(gVS)	Modified Gompertz parameters (model)			R^2	Rm
		P, l/(gVSd)	*Rm* , l/(gVSd)	λ,, (d)		
DWB	0.240	0.257	0.011	25.190	0.983	0.003
PW1	0.340	0.342	0.019	7.323	0.997	0.001
PW2	0.390	0.382	0.015	7.686	0.995	0.002
PW3	0.230	0.397	0.019	9.528	0.996	0.002
PW4	0.280	0.330	0.018	18.429	0.993	0.003

[a]Experimental final cumulative biogas yield

Observation can be made from Table 4 are as follows,

- Digesters PW1, PW2, PW3 and PW4 had the shorter lag period of 7.3238 days, 7.6761 days, 9.5288 days and 18.4293 days respectively while DWB had a longer lag period of 25.109 days.
- The digester PW3 exhibits higher biogas production rate (0.0199 l/(g VS d)) than PW1 (0.0193 l/(g VS d)), PW2 (0.0159 l/(g VS d)), PW4 (0.0185 l/(g VS d)) and DWB (0.0166 l/(g VS d)).
- The amount of gas reduced at the end of digestion period was highest for digester PW3 (0.39 l/(g VS)). However digesters PW1, PW2, PW3 and DWB produced 0.34 (l/(g VS)), 0.37 (l/(g VS)),0.32 (l/(g VS)) and 0.24 (l/(g VS)) of biogas respectively.

These results are expected due to the function of water in bio-digester since the TS content will directly correspond to water content. According to Sadaka and

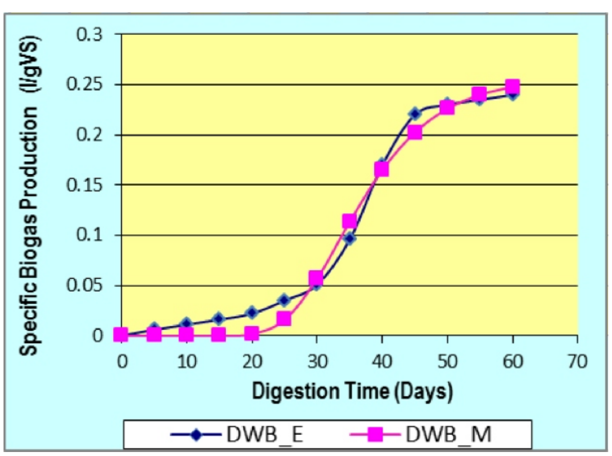

Fig. 2. Modified Gompertz equation fit for DWB

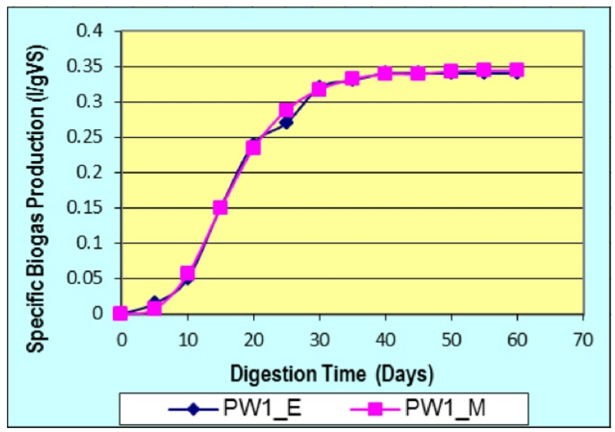

Fig. 3. Modified Gompertz equation fit for PW1

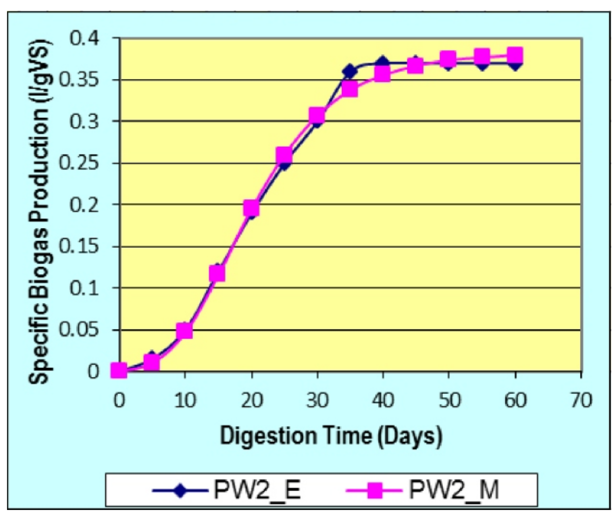

Fig. 4. Modified Gompertz equation fit for PW2

Engler (23) water content is one of very important parameters affecting anaerobic digestion of solid wastes. There are two main reasons. The first one

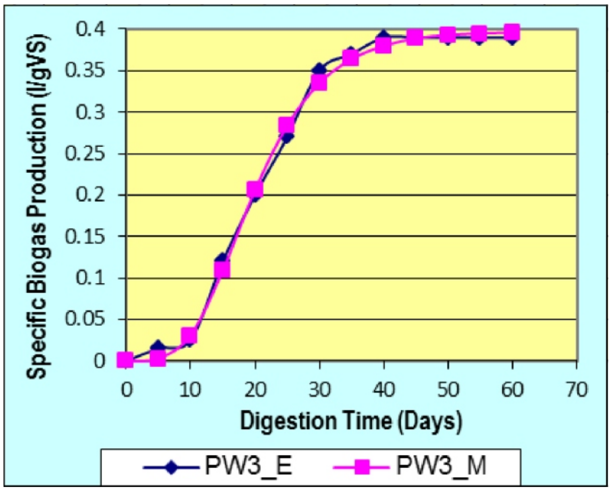

Fig. 5. Modified Gompertz equation fit for PW3

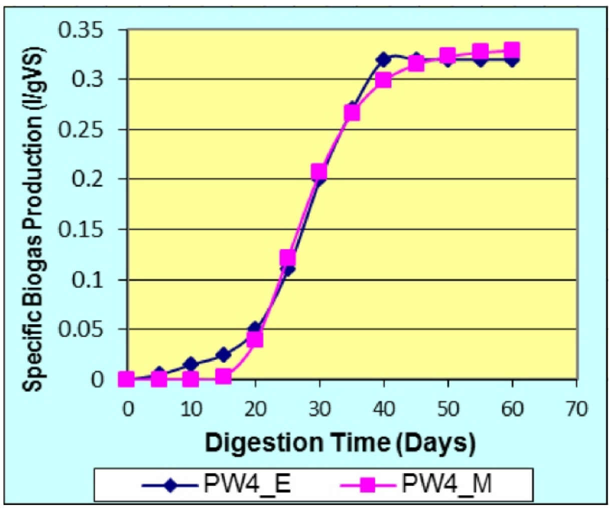

Fig. 6. Modified Gompertz equation fit for PW4

being that water makes possible the movement and growth of bacteria facilitating the dissolution and transport of nutrient while the second being that water reduces the limitation of mass transfer of non-homogenous or particulate substrate.

From Figures 3, 4 and 5 it is clear that modified Gompertz equation fits well to the experimental kinetic data for PW1, PW2 and PW3. However for DWB and PW4 during lag phase there is negative deviation observed between best fit and experimental data which is indicated in the lower value of R^2 and slightly higher value of Rmsd.

IV. CONCLUSION

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

- Among all the combinations of poultry litter with water hyacinth, PW3 produced the highest biogas with better production rate.
- Pretreatment of water hyacinth with acetic acid for biogas generation has indeed played an essential role, by breaking lignin fibers of water hyacinth and making them easily available for degradation by microorganisms,
- The use of enriched and pretreated water hyacinth for biogas generation therefore, will be a good energy source for those residing in the coastal areas, which face the menace of clogging of waterways by the weed.
- Anaerobic co-digestion of dried and ground water hyacinth with poultry litter enhanced biomethanation and produced more biogas when compared to blank digester.
- This performance confirms the earlier reports by other researchers that combining animal dung with plant wastes catalyzes the biogas production with consequent increased yield (24, 25, 26).
- The modified Gompertz equation best describes cumulative gas produced as a function of retention time.

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