Effect of Substrate Concentration on Biomethanation of Water Hyacinth

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***Abstract*—**Water hyacinth is a noxious weed that has attracted worldwide attention due to its fast spread and congested growth, which lead to serious problems in fishing, evapotranspiration, navigation, irrigation, power generation, reduction in dissolved oxygen and reduction in biodiversity. Attempts to control the weed have caused high costs and labor requirements, leading to nothing but temporary removal of the water hyacinths. In this study biomethanation of water hyacinth was carried out for 60 days at mesophilic condition by varying the substrate concentration from 3% to 11% in 250 ml biodigesters. 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 with 7% substrate concentration produced maximum biogas of 0.289 $l(g\ VS)^{-1}$ and kinetic parameters P, R_m and λ were 0.309 $l(g\ VS)^{-1}$; 0.0157 $l(g\ VS)^{-1}d^{-1}$ and 27.337 days respectively.

***Keywords*—**Biomethanation, cumulative biogas production, kinetic parameters, water hyacinth.

I. 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]. Biomethanation is a complex process consisting of a series of microbial reactions catalyzed by conglomerates of different bacteria [3] to convert organic wastes into biogas and a stable product (soil conditioner) for agricultural practices without any detrimental effects on the environment.

Water hyacinth and its tendency of fast growth would have a great potential if seen as a raw material for biogas production as it is rich in nitrogen, essential nutrients and has a high content of fermentable matter [4]. Apart from biogas the residual slurry obtained after anaerobic digestion is rich in essential inorganic elements which are good soil conditioners with no detrimental effects on the environment [5]. Numerous studies have been conducted by researchers to improve biomass conversion efficiency and biogas yield. The techniques include using different pre-treatment methods [6]; improving substrate composition by co-digesting with other substrates [7]; optimization of dilution on biomethanation of fresh water hyacinth [8] and effects of particle size, plant nitrogen content and inoculum volume [9]. This study focuses on optimization of substrate concentration on biomethanation of water hyacinth. Different quantities of moisture free water hyacinth were mixed with water in different combinations resulting in five different fermentation slurries. The digesters were labeled as DWH-3, DWH-5, DWH-7, DWH-9 and DWH-11 with their corresponding Total Solid (TS) content as 3%, 5%, 7%, 9% and 11%. As per the analysis, the best performance for biogas production was from the digester DWH-7 followed by DWH-9 and DWH-5. The data obtained from these experiments were further used to fit and check the fitness of the modified Gompertz model that describes kinetics of biomethanation process. These results indicate TS plays an important role and optimum TS range is 7 to 9%.

II. Materials And Methods

A. Sample Collection

Water hyacinth used for the study was obtained from silver lake at HBR layout (Bangalore, Karnataka, India).

B. Sample Analysis

Water hyacinth was analyzed for the following parameters

1) *pH analysis*: pH was measured by pH meter which consists of a 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.

2) Total solids (TS) and total Volatile Solids (VS): TS were determined at 104 ^{0}C to constant weight (Standard method part 2540 B) and VS were measured by the loss on ignition of the dried sample at 550 ^{0}C (Standard method part 2540 E) [10].

3) *Biogas analysis*: Gas chromatograph (Chemito 1000) equipped with a thermal conductivity detector was

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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 into 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. The concentrations of different components were calculated using equation (1):

$$\% \text{ of X} = \left(\frac{\text{Area of X in sample}}{\text{Area of X in standard}}\right) \times \% \text{ of X in standard} \quad (1)$$

C. Biomethanation Unit

Biomethanation unit consists of a temperature controlled thermo bath which is maintained at the mesophilic temperature range of 30°C to 35°C. It has a battery of bio-digesters. Each bio-digester is connected to a graduated gas collector by means of a connecting tube. Each of the gas collectors are in turn immersed in a trough of water to ensure complete sealing. A stand holds all the gas collectors. Biogas evolved is collected by the downward displacement of water. A schematic diagram of biomethanation unit is shown in Fig. 1.

D. Fermentation Slurry Preparation

Fresh water hyacinth (leaves, stem and root) on collection was chopped to small sizes of about 2cm and allowed to dry under the sun for a period of 7 days. They were then dried in an oven at 60^0C for 6hours. This oven-dried water hyacinth was ground to fine powder using a grinding mill. A series of laboratory experiments using 0.25l bio-digesters were performed in batch operation mode. Different quantities of moisture free dry water hyacinth were mixed with water in different combinations resulting in five different fermentation slurries. The digesters were labeled as DWH-3, DWH-5, DWH-7, DWH-9 and DWH-11 with their corresponding Total Solid (TS) content as 3%, 5%, 7%, 9% and 11%. Table I presents detailed content of digesters. Biomethanation of these digesters were carried out in duplication with a retention period of 60 days in the mesophilic range. Cumulative biogas production, slurry temperatures were monitored throughout the period of the study.

TABLE I
CONTENTS OF DIGESTERS

Digester	%	Water hyacinth (g)	Water (g)
DWH-3	3	3	97
DWH-5	5	5	95
DWH-7	7	7	93
DWH-9	9	9	91
DWH-11	11	11	89

E. Modified Gompertz Equation

The kinetic data obtained from all digesters were checked for the fitness of modified Gompertz equation [11]. The modified Gompertz equation, that gives cumulative biogas production from batch digesters assuming that biogas production, is a function of bacterial growth. The modified Gompertz equation is given by (2)

$$M = P \times \exp\left\{-\exp\left[\frac{R_m \times e}{P}(\lambda - t) + 1\right]\right\} \quad (2)$$

Where

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

P Biogas yield potential, l/(g VS)

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

λ Duration of lag phase, d (days)

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

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

Fig. 1 Biomethanation unit

III. Results And Discussion

A. Solids and pH Analysis

Total solids are the sum of suspended solids and dissolved solids. Total solids analysis and pH are important for assessing anaerobic digester efficiencies. TS analysis is done using standard methods while pH is measured using pH meter (Systronics). The TS are composed of two components, volatile solids and fixed solids. The VS are organic portion of TS that biodegrade anaerobically. Table II gives the solid analysis and pH data water hyacinth. TS and VS are calculated using (3) and (4).

$$\text{TS, \%} = \frac{(A-B)}{(D-B)} \times 100 \quad (3)$$

$$\text{VS, \%} = \frac{(A-C)}{(A-B)} \times 100 \quad (4)$$

Where

A is weight of dish + dried sample at 104^{0}C (g)

B is weight of dish (g)

C is weight of dish + sample after ignition at 550^{0}C (g)

D is weight of dish + wet sample (g)

B. Effect of Total Solid Content on Biomethanation

The cumulative biogas production with time for all the digesters is shown in Fig.2. It can be observed from Fig.2 biogas production rate tends to obey sigmoid function (S curve) as it generally occurs in batch growth curve.

The effect of total solids content on biogas production was studied by varying total solids from 3% to 11%. Fig. 2 shows cumulative biogas production of DWH-3, DWH-5, DWH-7, DWH-9 and DWH-11 as 0.192, 0.264, 0.289, 0.273 and 0.240 l/(gVS) respectively. The best performance for biogas production was from the digester DWH-7 (7%) followed by DWH-9 (9%) and DWH-5. These results suggest that, TS content affects the biogas yield. This is similar to the findings of Balsam that the optimum solid content is in the range 7-9 % for highest biogas production [12,13]. Furthermore, Baserja reported that the process was unstable below a total solids level of 7% while a level of 10% caused an overloading of the fermenter [14]. 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 Engler water content is one of very important parameters affecting biomethanation of solid wastes [15]. There are two main reasons. The first one 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.

TABLE II
SOLID ANALYSIS AND pH DATA

Material	% TS	% VS	pH
Water hyacinth	16.89	82.85	6.4

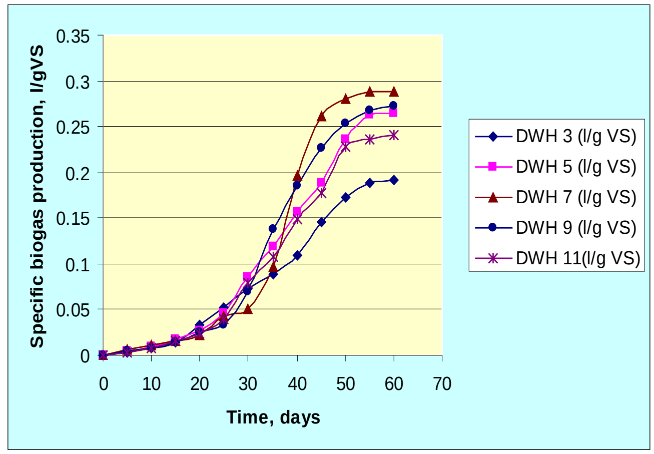

Fig. 2 Cumulative biogas production

C. Kinetics of Biogas production

With an assumption that biogas produced is a function of bacterial growth in batch digesters, modified Gompertz equation relates cumulative biogas production and the time of digestion through biogas yield potential (P), the maximum biogas production rate (Rm) and the duration of lag phase (λ) [16]. 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 III. and 7. From Table III the following observations were made.

- Lag phase (λ) for all the digesters ranged from 15.63 to 27.33 days. This suggests that water hyacinth by itself does not have the essential microbes to produce biogas early.
- The biogas production rate (R_m) for DWH-3 is the lowest of 0.00488 l/(g VS d) and the highest is shown by DWH-7 with a value of 0.0157 l/(g VS d).
- DWH-7 produced the maximum amount of biogas of 0.289 l/(g VS) followed by DWH-9 with a value of 0.273 l/(g VS).

TABLE III
SUMMARY OF PERFORMANCE OF DIGESTERS

Digester	Biogas Yield l/(gVS)	Modified Gompertz parameters (model)			R^2	Rmsd
		P, l/(gVS)	R_m, l/(gVS d)	λ, (d)		
DWH-3	0.20002	0.27497	0.004889	15.63	0.001	0.0013
DWH-5	0.27429	0.35094	0.007643	19.21	0.001	0.0017
DWH-7	0.30024	0.30935	0.015721	27.33	0.004	0.0043
DWH-9	0.27810	0.29632	0.011019	22.75	0.002	0.0020
DWH-11	0.24960	0.29926	0.007440	19.69	0.001	0.0019
DWH-3	0.20002	0.27497	0.004889	15.63	0.001	0.0013

The best fit to Gompertz equation is compared with experimental data in Fig. 3, 4, 5, 6 and 7. From these figures it is clear that modified Gompertz equation fits best to the experimental kinetic data.

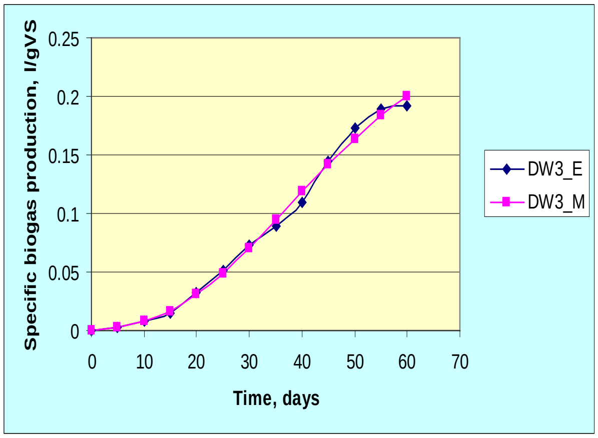

Fig. 3 Modified Gompertz equation fit for DWH-3

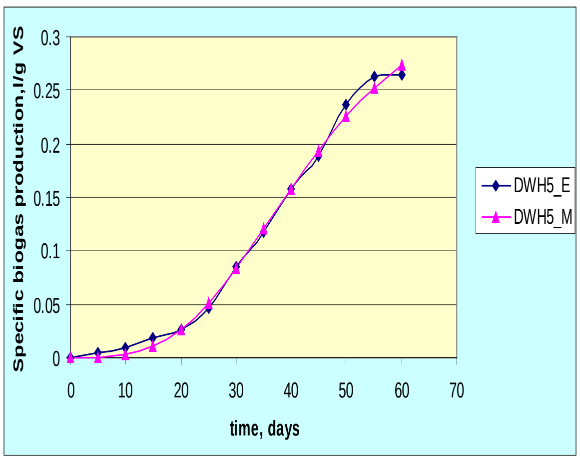

Fig. 4 Modified Gompertz equation fit for DWH-5

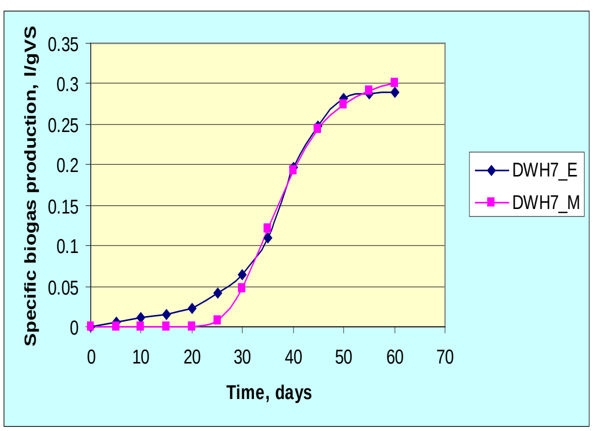

Fig. 5 Modified Gompertz equation fit for DWH-7

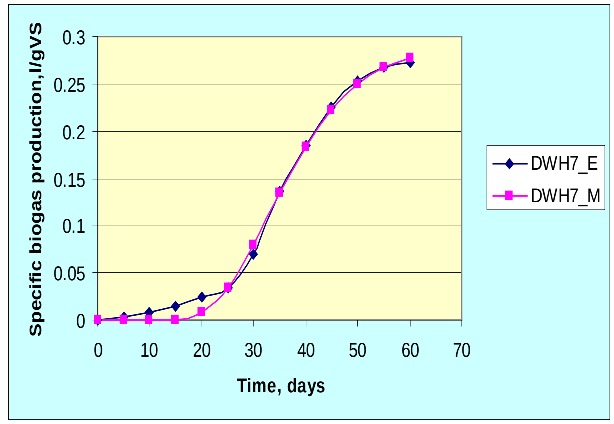

Fig. 6 Modified Gompertz equation fit for DWH-9

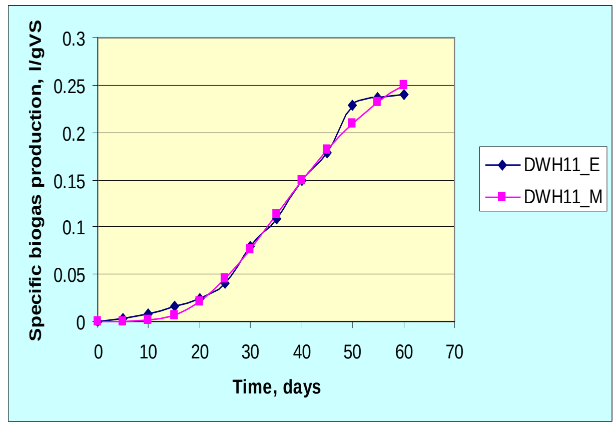

Fig. 7 Modified Gompertz equation fit for DWH-11

IV. Conclusions

The conclusions drawn in context to the use of primary sludge as inoculum were as follows:

- In today's energy demanding lifestyle, water hyacinth proves to be a promising renewable source of energy in the form of biogas.
- Water hyacinth by itself does not have the essential microbes to produce biogas early. Hence Anaerobic co-digestion of water hyacinth with primary sludge cow manure and poultry litter should be tried out.
- The best performance of biogas generation was observed in digester DWH-7. Indicating optimum substrate concentration is 7%.
- The graphs have verified that Modified Gompertz equation best describes cumulative gas produced as a function of retention time.
- Biogas can be utilized for electricity production on sewage works, in a CHP gas engine, where the waste heat from the engine is conveniently used for heating the digester. If compressed, it can replace compressed natural gas for use in vehicles, where it can fuel an internal combustion engine or fuel cells and is a much more effective displacer of carbon dioxide than the normal use in on-site CHP plants.

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