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Kinetic Modeling of Anaerobic Co-digestion of Water Hyacinth and Poultry Litter

Patil J.H.*, Molayan Lourdu Antony Raj, Bhagyashree, Vantimar Dinesh and Rohith
Department of Chemical Engineering, R.V. College of Engineering, Bangalore-560059, INDIA

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Abstract

The over-utilization of global energy sources is a major problem to the present and future world community. It has been estimated that the fossil fuels would be exhausted in the next few decades. In today's energy demanding lifestyle, there is always a need for exploring and exploiting new sources of energy which is renewable as well as eco-friendly. Anaerobic co-digestion is a technology that utilizes more than one organic waste to produce methane, which holds promise for the future while simultaneously addressing ecological and agrochemical issues. In the present study anaerobic co-digestion of water hyacinth and poultry litter has been carried out in 300 ml batch digesters with 8% total solids content for different retention period. After completion of the retention period of individual digester, total solids, volatile solids, pH and biogas evolved is been tabulated Variation of Biogas production, total solids, volatile solids, and pH has been studied as a function of time. Anaerobic co-digestion of Water Hyacinth and Poultry Litter produced biogas yield of 0.3810 l/g volatile solids. A kinetic model was proposed using integral method of analysis which revealed the anaerobic co-digestion of water hyacinth and poultry litter follows a first order reaction with rate constant 0.026 day^{-1}.

Keywords: Anaerobic co-digestion, water hyacinth, poultry litter, volatile solids, kinetic model.

Introduction

Energy is one of the most important factors to global prosperity. The dependence on fossil fuels as a primary energy source has led to global climate change, environmental degradation, and human health problems. It has been predicted that by the year 2040, the world will have a population of 9 to 10 billion people that must be provided with energy and materials[1]. Moreover, the recent rise in oil and natural gas prices may drive the current economy towards alternative energy sources. Anaerobic digestion is a biological process that converts organic matter into biogas which mainly consists of methane (55 to 75%) and carbon dioxide (25 to 45%) with calorific value of 20 MJ/m3[2-3]. The potential of this process is wide, because anaerobic digestion can be applied to a large variety of biodegradable organic waste and effluents from urban, industrial, or agricultural origins.

Co-digestion is the simultaneous digestion of more than one type of waste in the same unit[4]. 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[4-6]. Studies have shown that Co-digestion of several substrates, such as, 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[7-10]. Anaerobic co-digestion of water hyacinth and primary sludge was explored and found to improve biogas yield significantly[11]. Biomethanation of water hyacinth treated with poultry litter enhanced biogas yield[12]. In the present study anaerobic co-digestion of water hyacinth and poultry litter was carried out in 300 ml batch digesters with 8% total solids content for different retention period and a kinetic model was proposed to explain the kinetics of anaerobic co-digestion of water hyacinth and poultry litter.

Material and Methods

Collection of Substrates: Water hyacinth was obtained from a lake near Kengeri Upanagara (Bangalore, Karnataka, India).Fresh poultry litter sample was obtained from Chandru Poultry Farm, Ullal Upanagara (Bangalore, Karnataka, India).

Materials and Apparatus: The following materials and apparatus were used for the purpose of this research: weighing balance(Systronics), pH meter (Systronics), a mercury in glass thermometer (range 0^0C to 100^0C), muffle furnace, oven, mixer grinder, temperature controlled water bath, water troughs, graduated transparent glass gas collectors, tap water, rubber cork, connecting tubes and Tap water.

Experimental set up: Experimental set up consists of a constant temperature bath with a provision to maintain desired temperature. A battery of digesters each of volume 300ml was kept in the temperature bath which was maintained in the mesophilic temperature range from 30°C to 35°C. Each bio-digester was connected to a graduated gas collector by means of a connecting tube. Each of the gas collectors were in turn

immersed in a trough containing water to ensure complete water sealing. A stand held all the gas collectors such that the water displacing hole at the bottom end immerses in water. Biogas evolved was collected by the downward displacement of water. The experimental set up for biomethanation is shown in figure-1.

Pretreatment of water hyacinth: Fresh water hyacinth (leaves, stem and root) on collection was 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. The oven-dried water hyacinth was then ground to fine particles using a mixer grinder[12]. Then sieve analysis of water hyacinth powder was done using a sieve of mesh number 22.

Preparation of fermentation slurry: Based on material balance 2880 g. of fermentation slurry with 8% total solids content was prepared by mixing 112g. of pretreated water hyacinth, 563.68g. of poultry litter and 2204.16 g. of water. 180 g. of resultant slurry was transferred to 300ml digesters of different retention period. Each digester was given 5ml of 10% by volume of acetic acid and 1.7g sodium bicarbonate. Anaerobic co-digestion of digesters were carried out in duplication till completion of their retention period in the mesophilic temperature range.

Analytical methods: Solids analysis**:** Total solids (TS) and volatile solids (VS) were determined for water hyacinth and poultry litter according to standard methods[13].

pH analysis**:** pH was measured using a pH meter which consisted 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.

Integral analysis method: Integral method of analysis was used to propose a kinetic model and determine the order and rate constant of co-digestion of water hyacinth and poultry litter. The reaction was assumed to be first order, rate for which is, $(-r_A) = k\, C_A$

Where C_A is the concentration of volatile solids.

Integrating with suitable limits gives rate equation-$\ln (C_A/ C_{A0})$= kt. If plot of $-\ln(C_A/ C_{A0})$ against't' gives a straight line passing through origin, then it can be inferred that the reaction follows a first order kinetics with slope equal to rate constant k. Otherwise assume a different rate expression and repeat the procedure.

Results and Discussion

Solids and pH Analysis: Total solids (TS) were determined after drying in oven overnight at 105^0C. Volatile solids (VS) were determined by igniting the dried sample at 550^0C for 2 hours and determining the ash free dry weight. Total solids and Volatile solids are calculated as given bellow.

$$TS, \% = \frac{W_{total} - W_{dish}}{W_{sample} - W_{dish}} * 100 \quad and VS, \% = \frac{W_{total} - W_{volatile}}{W_{total} - W_{dish}} * 100$$

Where, W_{total} is weight of dish and dried sample at 103^0C to 105^0C in grams. W_{dish} is weight of the dish in grams. W_{sample} is weight of the dish and wet sample in grams. $W_{volatile}$ is weight of the dish and sample after ignition at 550^0C in grams.

The total solids, volatile solids, and pH data of water hyacinth and poultry litter are presented in table-1.

Table-1
Total solids,Volatile solids, and pH data

Material	% TS	% VS	pH
Water Hyacinth	16.89	82.84	6.5
Poultry Litter	21.00	83.47	6.0

Biogas production: The biogas production ,total solids, volatile solids, and pH were determined for each digester after the expiry of their retention period; the values are tabulated in table-2. The variation of specific biogas production, pH and solids with time are presented in figures-2, figure-3 and figure-4 respectively.

Table-2
Cumulative biogas production, TS, VS, and pH data for all the digesters

Digester	Biogas yield (liters/gVS)	Total Solids (g)	Volatile Solids (g)	pH
WH-PL-0	-	14.4	11.88	7.0
WH-PL-7	0.0388	12.959	11.029	6.5
WH-PL-14	0.0494	12.626	10.797	6.5
WH-PL-21	0.1074	11.191	9.524	6.5
WH-PL-28	0.2172	8.362	7.117	6.5
WH-PL-35	0.3490	4.965	4.226	6.5
WH-PL-42	0.3664	4.517	3.845	7.0
WH-PL-49	0.3776	4.228	3.599	7.0
WH-PL-56	0.3810	4.187	3.564	7.0

From figure-2 it is clear that biogas produced was a function of bacterial growth in the digesters and followed a sigmoid curve. Distinctly three phases of microbial growth (lag, exponential and death) can be visualized. The rate of specific gas production was very less initially for 15 days which represents a greater lag phase of hydrolysis. This gas production rate increased from15 to 40 days. Later the rate increased steadily to attain highest biogas yield of 0.3810 l/g VS. pH is very important parameter that controls biomethanation process. It can be inferred from figure-3 that pH of the slurry was maintained in the neutral range throughout the retention period which is essentially because of the addition of buffering agent. It is seen from figure-4, that volatile solids undergo biodegradation with the

digestion time to evolve biogas. Observation also reveals that the rate volatile solid depletion is directly proportional to microbial growth rate.

Kinetics of co-digestion: Integral method was employed to determine the value of the rate constant for co-digestion of water hyacinth and poultry litter. The plot of -ln C_A/ C_{A0} versus digestion time is shown in figure-5. This plot yields a straight line passing through the origin which indicates that anaerobic co-digestion of water hyacinth and poultry litter follows a first order reaction. The slope of the straight line gives rate constant, k. A 'C' program with method of least squares was written to evaluate the rate constant, k which was found to be 0.026day^{-1}.

Figure-1
Experimental set up for Biomethanation

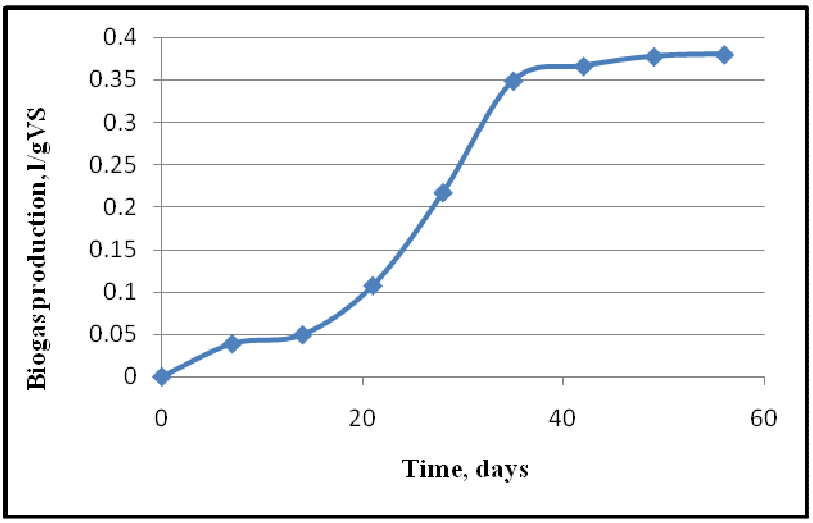

Figure-2
Cumulative biogas production

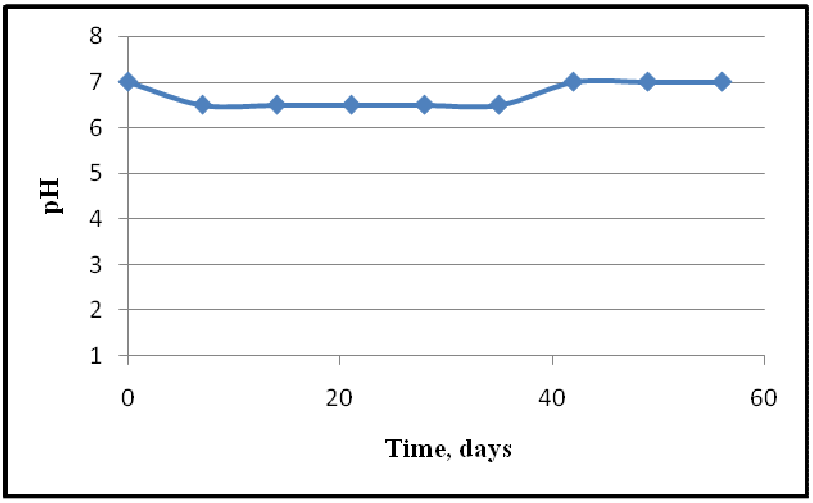

Figure-3
Variation of pH

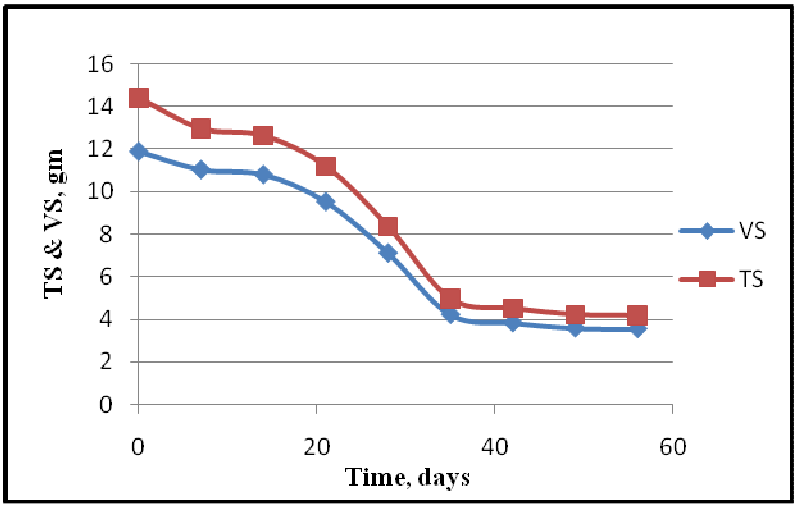

Figure-4
Variation of TS and VS

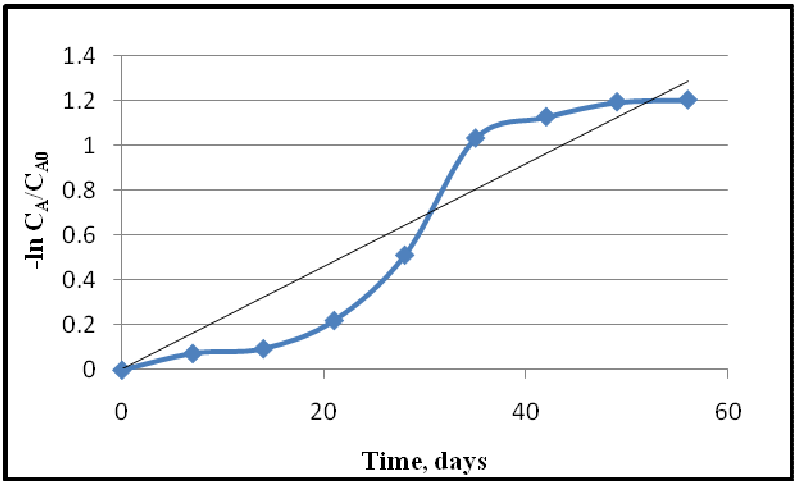

Figure-5
Plot of -ln C_A/ C_{A0} versus digestion time

Conclusion

From the study presented in this paper, the following conclusions are made. Anaerobic co-digestion of water hyacinth with poultry litter was explored and was found to produce good amount of biogas (0.3810 l/g of VS). Variation of key parameters (TS, VS & pH) with time was studied. Co-digestion of water hyacinth and poultry litter follows first order reaction with rate constant $0.026day^{-1}$. However figure-5 shows a negative gradient initially and a positive gradient towards the end. These gradients are because of the three phases namely lag phase, exponential phase and death phase. This gives further scope for the researchers to understand the kinetics of individual phases, which could explain the co-digestion of water hyacinth and poultry litter in most appropriate way.

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14. Method 1684 total, fixed, and volatile solids in water, solids, and biosolids. U.S. Environmental protection agency office of water, office of science andtechnology, engineering and analysis division (4303), 1200 Pennsylvania Ave.NW, WASHINGTON, DC 20460 **(2013)**