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Kinetic study on the effect of temperature on biogas production using a lab scale batch reactor

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ABSTRACT

In the present study, biogas production from food waste through anaerobic digestion was carried out in a 2 l laboratory-scale batch reactor operating at different temperatures with a hydraulic retention time of 30 days. The reactors were operated with a solid concentration of 7.5% of total solids and pH 7. The food wastes used in this experiment were subjected to characterization studies before and after digestion. Modified Gompertz model and Logistic model were used for kinetic study of biogas production. The kinetic parameters, biogas yield potential of the substrate (B), the maximum biogas production rate (R_b) and the duration of lag phase (λ), coefficient of determination (R^2) and root mean square error (RMSE) were estimated in each case. The effect of temperature on biogas production was evaluated experimentally and compared with the results of kinetic study. The results demonstrated that the reactor with operating temperature of 50 °C achieved maximum cumulative biogas production of 7556 ml with better biodegradation efficiency.

1. Introduction

Biomass has been considered as a major source of renewable energy to replace the fast declining fossil fuel resources (Demirbas, 2007; Ozcimen and Karaosmanoglu, 2004; Jefferson, 2006). Biomass appears to be an attractive feedstock for three main reasons. First, it is a renewable resource that could be sustainably developed in the future. Second, reportedly it has positive environmental properties resulting in no net release of carbon dioxide (CO_2) and very low sulfur content. Third, it also has significant economic potential provided that, fossil fuel prices continuously increase in the future (Cadenas and Cabezudo, 1998). Production of biofuels from biomass can slow down the climate change by substantially reducing the greenhouse gas emissions (Meena et al., 2011). Among various renewable technologies, anaerobic digestion is a commercially proven and widely employed technology for treating biomass, especially like agricultural and forest residues, municipal solid waste, etc. (Meena et al., 2011).

Anaerobic digestion is a natural process by which complex organic materials are broken down into simpler compounds in the absence of air by several micro-organism communities (Samir et al., 2010; Cioabla et al., 2012). Anaerobic digestion comprises of a series of four biochemical reaction steps: hydrolysis – hydrolytic bacteria breaks down polymers to monomers; acidogenesis – acidogenic bacteria converts monomers to short chained carboxylic acids, carbon dioxide, hydrogen and alcohol; acetogenesis – the products of the previous steps are converted to acetic acid; methanogenesis – methane is produced from the acetic acid (Weiland, 2010; Kumar et al., 2010; Decker and Menrad, 2007; Barik et al., 2013).

The major advantage of the anaerobic digestion process is the production of biogas, a renewable energy source, which can be used as fuel for automobiles, for direct heating and for power generation (Appels et al., 2011). The production of biogas, depending on the biomass feedstock used, helps in the reduction of fossil fuel usage and enables the lowering of carbon dioxide levels. Apart from biogas yield, anaerobic digestion liberates solid and liquid by-products which can be used as fertilizer or soil amendment.

The biogas produced during anaerobic digestion process is a blend of methane (CH_4: 55–65% by volume), carbon dioxide (CO_2: 30–40% by volume), and traces of hydrogen sulphide (H_2S), hydrogen (H_2) (Deepanraj et al., 2014). Due to the intricacy of the bioconversion processes, various factors like solid concentration, pH, temperature, mixing/agitation, C/N ratio, etc. are affecting the performance of an anaerobic digestion process. Among those factors, temperature is one of the important factor and lot of researchers investigated the effects of temperature on biogas production using various feedstock and reported their findings (El-Mashad et al., 2004; Ji-Shi et al., 2006; Vanegas and Bartlett, 2013;

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Ghatak and Mahanta, 2014). The present study aims to investigate the effect of temperature on biogas production from food waste experimentally in an anaerobic batch digester. The experimental kinetics was also analyzed for the goodness of fit with modified Gompertz model.

2. Materials and methods

2.1. Feedstock

Food waste used in this experimental study was collected from a hostel mess of National Institute of Technology Calicut, Kerala. Food waste is a highly desirable substrate for anaerobic digestion with regards to its higher biodegradability and biogas/methane yield. This contains a substantially large amount of organic matter, which can be digested anaerobically to produce biogas. Also, the nutrient content analysis showed that the food waste contained well balanced nutrients for anaerobic microorganisms ([Zhang et al., 2007,Zhang et al., 2012]). The elemental composition of the food waste was determined using elemental analyzer. The carbon, hydrogen, oxygen, nitrogen and sulfur compositions present in the feedstock are 49.96%, 10.35%, 1.13%, 38.28% and 0.28% respectively. The food wastes obtained were shredded, mixed and stored at 5 °C until it is introduced into the anaerobic digester. The solid concentration and pH values were already optimized in the previous experiments (Deepanraj et al., 2014; Jayaraj et al., 2014). Water was added to obtain the desired total solid concentration (7.5% of total solids) and 1 N sodium bicarbonate solution was used to maintain the pH value as 7. The characteristics of the substrate used were determined before and after digestion. For all the experiments, cow dung was used as inoculum (10% inoculum to feed ratio).

2.2. Experimental setup

Laboratory-scale anaerobic batch digesters made of glass with a total volume of 2 l and working volume 1.6 l were used in all the experiments. Biogas production from the digesters was measured daily by the water displacement method. The reaction mixtures were stirred twice a day. Each reactors were maintained with different temperatures (30, 40, 50 and 60 °C) using water bath.

2.3. Analytical methods

Characterization of feedstock is one of the most significant steps in the biogas production process. Determining the general composition of the substrate (input feed) is essential for calculating the quantity and composition of the biogas generated. The total solids, volatile solids, fixed solids and chemical oxygen demand of the substrate and digestate were determined as per the standard method (APHA Standard methods for examination of water and waste water, 1989). Total dissolved solids were determined using TDS meter (Model-161, Deep Vision Instruments, India) and pH of the substrate and digestate was determined using pH meter (pH-201, Lutron Electronic Enterprise, Taiwan). The elemental composition was determined using elemental analyzer (Elementar Vario EL III, ELEMENTAR Analysensysteme, Germany). The methane and carbon dioxide composition in the biogas were measured using infrared gas analyzers (PIR-89, Technovation Analytical Instruments, India).

2.4. Kinetic study

Many dynamic models are available to give a detailed description of bioconversion mechanism. In this study, we used modified Gompertz model and Logistic model. Using these models, the biogas production potential of the substrate, maximum biogas production rate and the lag phase of the reaction can be determined with available experimental results. The kinetic data obtained from all digesters were checked for the fitness of modified Gompertz model and Logistic model. The modified Gompertz model and Logistic model describes cumulative biogas production from batch digesters, assuming that biogas production is a function of bacterial growth (Nopharatana et al., 2006; Pommier et al., 2007). The equations are given by

$$C = B\exp\left\{-\exp\left[\frac{R_b e}{B}(\lambda - t) + 1\right]\right\} \quad (1)$$

$$C = \frac{B}{1 + \exp\left[4R_b\frac{\lambda - t}{B} + 2\right]} \quad (2)$$

where 'C' is cumulative biogas production at digestion time 't' days; 'B' is biogas yield potential of the substrate; 'R_b' is maximum biogas production rate; 'e' is exp (1)=2.718; 'λ' is the duration of lag phase.

The kinetic parameters of each of the reactor were estimated using nonlinear least-square regression analysis with the help of

Table 1
Characteristics of substrate and digestate.

Characteristics	Substrate	Digestate			
		30 °C	40 °C	50 °C	60 °C
TS (g/l)	75	37.92	36.28	34.23	35.17
VS (g/l)	71.34	35.02	34.00	31.02	32.74
FS (g/l)	3.66	2.90	2.28	1.4	0.53
TDS (g/l)	0.732	1.78	1.90	2.12	2.08
COD (g/l)	69.92	42.70	40.17	37.95	38.88

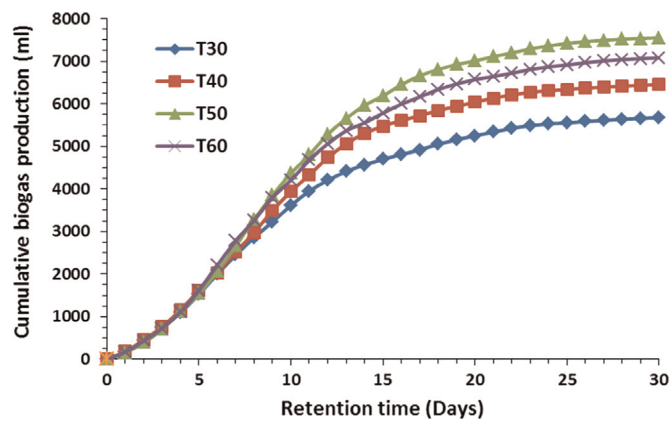

Fig. 1. Cumulative biogas production.

Table 2
Results of experimental study.

Parameter	30 °C	40 °C	50 °C	60 °C
TS removal efficiency (%)	49.44	51.62	54.36	53.10
TS removed (g/l)	37.08	38.72	40.77	39.83
VS removal efficiency (%)	50.91	52.34	56.51	54.16
VS removed (g/l)	36.32	37.34	40.32	38.70
COD removal efficiency (%)	38.93	42.54	45.72	44.39
COD removed (g/l)	27.22	27.22	29.75	31.27
Cumulative biogas produced – experimental (ml)	5673	6449	7556	7081
CH_4 (%)	60.8	60.5	61.2	59.1
CO_2 (%)	36.3	38.0	37.1	38.5