Available online at www.sciencedirect.com
ScienceDirect
Biomass and Bioenergy 31 (2007) 80–86
BIOMASS & BIOENERGY
www.elsevier.com/locate/biombioe

Mathematical modeling for the prediction of biogas generation characteristics of an anaerobic digester based on food/vegetable residues

J. Biswas, R. Chowdhury*, P. Bhattacharya

Chemical Engineering Department, Jadavpur University, Kolkata 700 032, India

Received 1 June 2004; received in revised form 19 May 2006; accepted 3 June 2006
Available online 8 September 2006

Abstract

An anaerobic digester of 10 L capacity has been operated in batch mode at an optimum temperature of 40 °C and at a pH of 6.8 using vegetable/food residues as the feed material. The effect of slurry concentration and that of the concentration of carbohydrate, protein and fat in the slurry on the biogas production rate and methane concentration in the biogas have been studied. The slurry concentration has been varied in the range of 72.0–700 kg m^{-3}. At a slurry concentration of 67.7 kg m^{-3} the effect of carbohydrate concentration has been studied by varying the ratios of carbohydrate, protein and fat in the range of 6.9:4.3:1–12.1:4.3:1 by using a sole carbohydrate source, namely sucrose. The effect of protein concentration has been studied by varying the ratios of carbohydrate, protein and fat in the range of 5.6:7.0:1–5.6:13.0:1 by using a sole protein source, namely papain and that of fat concentration has been studied by varying the ratios of carbohydrate, protein and fat in the range of 7.2:10:1.6–7.2:10:5 by using a fat source, namely vanaspati. A deterministic mathematical model using differential system equations have been developed and it is capable of predicting the behaviour of the digester satisfactorily.

Keywords: Food residues from municipal market; Microbial treatment; Methane content of biogas; Effect of carbohydrate; Protein and fat; Deterministic model

1. Introduction

In the present investigation pretreated vegetable/food residues has been used as substrate for bio-energy generation. From the literature survey it is observed that a considerable amount of work is in progress towards producing biogas from municipal solid residues. However, very little information available on the biodegradation of vegetable/food residues demands two-fold emphasis of research in this area—firstly, to explore the possibility of using these residues as feed stock for biogas generation and secondly to evaluate reaction engineering parameters in both batch and continuous mode of reactors. Such investigations have paved the path to follow for more systematic work towards understanding reaction engineering behaviour of the present system which in turn may lead to the development of kinetic model equations necessary for subsequent bio-reactor design. In a few pioneering works on organic waste gasification Angelidaki and co-workers [1–4]; Angelidaki [2], Hanaki [5] and Andrews [6] revealed the mechanism of microbial and enzymatic degradation during the process. The kinetic parameters of the relevant biochemical reactions have also been reported in case of cow-dung gasification.

In the present investigation a systematic and programmed bio-reaction engineering studies have been carried out using vegetable/food residues of local municipal market as the raw material in a batch bio-digester. An attempt here has been made to develop kinetic model equations to predict dynamic response of the digester with respect to the concentration of target biogas methane and total biogas generation rate under varying concentration of carbonaceous substances namely, carbohydrate, protein and fat. Effect of slurry concentration on the biogas yield and quality with respect to the concentration of methane has also been studied systematically.

*Corresponding author. Tel.: +91 33 2414 6378; fax: +91 33 2414 6378.
E-mail address: ftbe_bon@yahoo.com (R. Chowdhury).

0961-9534/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2006.06.013

Nomenclature

ks	saturation constant ($kg\,m^{-3}$)
c	concentration ($kg\,m^{-3}$)
ki	inhibition constants ($kg\,m^{-3}$)
X	biomass concentration ($kg\,m^{-3}$)
μmax	maximum specific growth rate (d^{-1})
Y	yield coefficients as kilogram material consumed or produced/kilogram of biomass synthesized
HAc	acetic acid
HPr	propionic acid
Hbu	butyric acid
Hval	valeric acid
LCFA	long chain fatty acid
Sl	slurry
Carb	carbohydrate
Pr	Protein

Subscripts

I	related to acidogenic degradation of carbohydrate
II	related to acidogenic degradation of amino acid
III	related to acidogenic degradation of fat
IV	related to acetogenic degradation of propionic acid
V	related to acetogenic degradation of butyric acid
VI	related to acetogenic degradation of valeric acid
VII	related to acetogenic degradation of LCFA
VIII	related to aceticlastic degradation of acetic acid
1	related to carbohydrate in acidogenic/acetogenic/aceticlastic steps
2	related to protein in acidogenic/acetogenic/aceticlastic steps
3	related to fat in acidogenic/acetogenic/aceticlastic steps
4	related to HAc in acidogenic/acetogenic/aceticlastic steps
5	related to HPr in acidogenic/acetogenic/aceticlastic steps
6	related to HBu in acidogenic/acetogenic/aceticlastic steps
7	related to HVal in acidogenic/acetogenic/aceticlastic steps
8	related to LCFA in acidogenic/acetogenic/aceticlastic steps
9	related to CO_2 in acidogenic/acetogenic/aceticlastic steps
10	related to NH_3 in acidogenic/acetogenic/aceticlastic steps
11	related to H_2S in acidogenic/acetogenic/aceticlastic steps
12	related to CH_4 in acidogenic/acetogenic/aceticlastic steps
13	related to H_2O in acidogenic/acetogenic/aceticlastic steps

Using mechanistic approach and suitable differential mass balance equations a comprehensive simulation work has been carried out to describe the response of the biodigester. A unified approach has been made to develop a set of model equations that are general in nature and are capable of predicting the desired response simply by selecting suitable kinetic parameters. Attempt has also been made to avoid adjustable parameters in the model equations and to use simulation parameters, which can either be found out by simple experiment or are available in the literature. These deterministic experimental data have been obtained by judiciously selecting the reaction conditions. It is observed that the simulated data obtained from the proposed model equations fit well with the experimental data. It is thus expected that such studies would lead to a better concept of anaerobic biodegradation of market waste, which can later be utilized for design and scale up purposes.

2. Materials

Food/vegetable residues, comprised mainly residues of various vegetables, oil cakes from mustard oil mills and effluent acid whey of local sweet-meat shops. The typical composition of feed material is given in Table 1. Papain, vanaspati oil and sucrose were also used.

3. Analytical

Determination of total solid (TS), volatile matter (VM), carbohydrate, fat and protein.

The TS and the VM of vegetable/food residues, oil cake and whey were determined by standard methods (AOAC [7]). Content of carbohydrate, fat and protein were determined using standard methods (AOAC [7], [8]).

3.1. Analysis of biogas

The product biogas composition was analysed by gas chromatograph (CHEMITO Model No. 8510) using thermal conductivity detector (TCD) with a Porapaq–*q* column (Netel Chromatographs length 2 m, mesh size range 80/100). Hydrogen was used as a carrier gas at a flow rate of 20 mL/min. The oven, injector and detector temperatures were maintained at 60, 80 and 80 °C, respectively. In the present investigations all the gas volumes have been reported at NTP.