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BIOGAS HOME-PRODUCTION ASSESSMENT USING A SELECTIVE SAMPLE OF ORGANIC VEGETABLE WASTE. A PRELIMINARY STUDY

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SUMMARY

Biogas generation plants using organic waste are a daily reality that can be observed in different areas of waste disposal that exist in many cities of the world. In fact, the generation of biogas through anaerobic bio-digestion of urban wastes has a high impact in terms of energy use and reduced environmental liabilities. The present study focuses on the assessment of biogas production for domestic consumption; several biodigesters were tested in order to evaluate the biogas production under standard pressure and temperature. The test estimates volume of biogas being produced, substrate pH and substrate concentration, using different types of catalysts. A test bed was designed for testing three digesters (A, B and C) within recycled bottles of polyethylene terephthalate (PET), whose maximum volume is ~0.6 liters. A 60g organic substrate compound was placed in each bottle. The organic compound consisted of peeling residues of potatoes, cabbage and carrots. Experimental characterization of the mixture allowed to observe the production of biogas for domestic use, system temperature, pH levels achieved, mass and substrate concentration, as well as concentration and volume of the catalyst. Further studies, with a larger sample and monitoring the container pressure are recommended in order to establish a more precise relation among the whole set of experimental parameters.

Introduction

The organic waste biogas generation is a fact of life today, as a significant accumulation of organic residues lies in many urban sites without any useful application. These residues are within the so-called municipal solid waste (any product or substance resulting mainly from human activity without being harvested), which, amongst other aspects, generate a considerable air pollution in the vicinity of the disposal sites, through generation of gases like methane and carbon dioxide, largely responsible for the greenhouse effect (IDB, 1997).

This environmental liability can be reduced if this type of waste generated by any human activity receives an appropriate use, as, for example, through the production of biogas as an alternative energy source (Lansing *et al*., 2008).

The production of renewable energy through anaerobic fermentation of animal and vegetable waste under

KEYWORDS / Anaerobic Digestion / Biodigesters / Biogas / Biomethane Potential Measurement / Substrate /
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VALORACIÓN DE LA PRODUCCIÓN DE BIOGÁS PARA USO DOMÉSTICO EN UNA MUESTRA SELECTIVA DE DESECHOS ORGÁNICOS VEGETALES. ESTUDIO PRELIMINAR

Martín Durán-García, Yrina Ramírez, Ricardo Bravo and Luis Rojas-Solórzano

RESUMEN

La generación de desechos orgánicos vegetales es una realidad cotidiana que se puede observar en los diferentes espacios de disposición final de desechos que se encuentran en las urbes de los países del mundo. Sin embargo, la generación de biogás a través de la biodigestión anaeróbica de estos desechos representa una alternativa de alto impacto en cuanto al aprovechamiento energético y disminución de pasivos ambientales se refiere. En el presente trabajo se evaluó la producción de biogás de uso doméstico a través del uso de un banco de pruebas de biodigestores, con el objeto de valorar la producción de biogás a condiciones termodinámicas estándar de presión y temperatura, estimar el volumen de biogás producido, pH del sustrato, concentración del sustrato, tipo de catalizador, etc. Se construyó un banco de pruebas a escala para ensayar tres biodigestores (A, B y C) con probetas de polietileno-tereftalato (PET), cuyo volumen máximo es de ~0,6 litros. En cada biodigestor se colocó 60g de sustrato orgánico compuesto por conchas desechadas de papas, repollo y zanahoria. La caracterización experimental de la mezcla permitió observar la producción del biogás con fines de uso doméstico, temperatura del sistema, niveles alcanzados de pH, masa y concentración del sustrato; así como la concentración y volumen del catalizador. Se recomienda profundizar en estudios similares, aumentando la muestra y unificando criterios de medición, y en la caracterización en términos de presiones de los contenedores PET para estos estudios.

VALORIZAÇÃO DA PRODUÇÃO DE BIOGÁS PARA USO DOMÉSTICO EM UMA AMOSTRA SELETIVA DE DETRITOS ORGÂNICOS VEGETAIS. ESTUDO PRELIMINAR

Martín Durán-García, Yrina Ramírez, Ricardo Bravo e Luis Rojas-Solórzano

RESUMO

A geração de detritos orgânicos vegetais é uma realidade cotidiana que pode ser observada nos diferentes espaços de disposição final de detritos que se encontram nas cidades dos países do mundo. Entretanto, a geração de biogás através da biodigestão anaeróbica destes detritos representa uma alternativa de alto impacto em relação ao aproveitamento energético e diminuição de passivos ambientais. No presente trabalho é avaliada a produção de biogás de uso doméstico a través do uso de um banco de provas de biodigestores, com o objeto de valorizar a produção de biogás a condições termodinâmicas padrão de pressão e temperatura, estimar o volume de biogás produzido, pH do substrato, concentração do substrato, tipo de catalizador, etc. Construiu-se um banco de provas em escala para ensaiar três biodigestores (A, B e C) com provetas de polietileno-tereftalato (PET), cujo volume máximo é de ~0,6 litros. Em cada biodigestor foi colocado 60g de substrato orgânico composto por cascas descartadas de batatas, repolho, cenoura e batatas. A caracterização experimental da mistura permitiu observar a produção do biogás com fins de uso doméstico, temperatura do sistema, níveis alcançados de pH, massa e concentração do substrato; assim como a concentração e volume do catalizador. Recomenda-se aprofundar em estudos similares, aumentando a amostra e unificando critérios de medição, e na caracterização em termos de pressões dos recipientes PET para estes estudos.

certain pressure and temperature conditions, is capable of producing methane gas in proportional amounts to the available waste (Lansing *et al*., 2008).

Biogas contains a high percentage (50-70%) of methane (CH4), making it susceptible to be used as a source of energy for combustion engines, turbines or boilers, either alone or mixed with other fuels. In turn, the controlled process of anaerobic digestion is one of the most suitable for reducing greenhouse gas emissions, promote the use of organic waste for energy, and the maintenance and enhancement of fertilizer value of the processed products (Köttner *et al*., 2003; Chami and Vivanco, 2007; Lansing *et al*., 2008).

In this study, organic solid waste was collected and placed inside recycled containers for the biodigestor experimentation. The recycled containers consist in 0.6-liter polyethylene terephthalate (PET) bottles that are cleaned and rinsed after the use for which they were originally intended (eg., soda beverages). Using recycled PET containers improves the economy and feasibility of the project, since it reduces the costs of the digestors and the environmental impact of the project, as well as, taking advantage of simple and innovative digestors that have been certified as containers (PET plastic bottles) under considerable pressure conditions (COVENIN, 1988).

The anaerobic bio-digestion process uses mainly harmless substances that play the role of catalysts; for example, water is the most widely used catalyst in this type of processes. However, this study uses two safe catalysts such as boric acid and sodium bicarbonate, diluted to 5% w/v, which have been proven to accelerate the process above typical water-based systems (Chellapandi *et al*., 2008).

The present paper addresses the assessment of the biogas production from selected organic residues under controlled conditions of pressure, temperature, pH, substrate and catalyst type/concentration, in recycled PET containers.

Reference Framework

Biogas is a form of renewable energy which can be obtained as methane gas through the anaerobic fermentation of animal and vegetable waste under certain pressure and temperature conditions. The production of biogas is proportional to the amount of available waste (Lansing *et al*., 2008).

Anaerobic digestion is a biological process in which organic matter in the absence of O_2, and by the action of a specific group of bacteria, breaks down into biogas (CH_4, CO_2, H_2, H_2S, etc.), while digesting a mixture of mineral products (N, P, K, Ca, etc.) and degradating hard compounds (Kujawa-Roeleveld *et al*., 2003; Chami and Vivanco, 2007; Chellapandi *et al*., 2008; García, 2009).

The energy use, physical characteristics and low cost of biogas production from organic wastes motivates the study of this process. Biogas has a great potential in households, automotive industry, heating and power production applications, among others, and its heat power, valued around $22.32 MJ\cdot m^{-3}$, makes it a very important fuel (Köttner *et al*., 2003; Kujawa-Roeleveld *et al*., 2003; López, 2006; Chami and Vivanco, 2007; Lansing *et al*., 2008).

The anaerobic digesters are basically sealed containers of different shapes: cylindrical recipients, tubular reactors, oval tanks, among others, through which the organic sample enters properly wetted before being treated. Within an oxygen-free space, anaerobic bacteria multiply and process organic matter, producing methane gas.

In the anaerobic bio-digestion process a harmless catalyst substance may be used. The catalysts are characterized by stabilizing compounds that in some way regulate the formation of bacteria in the corresponding stages of the bio-digestion and by acting as conditioner agents for the pH, which should be ~7 for the biodigestion to be carried out (Chellapandi *et al*., 2008; García, 2009).

In particular, the sodium bicarbonate contributes to the formation of CH_4 and CO_2 when in the presence of acids, and the proportion of dissolved catalyst volume to digester volume does not exceed 10%. However, boric acid has the ability to reduce bacteria generated in the biodigestion, achieving a purifying effect (García, 2009). Therefore, one of the objectives of this study is to quantify the effect of both of these inoculants on the anaerobic digestion test proposed herein.

Methods

Experimental set up

Biodigestion tests were prepared in three different substrates consisting of 60g of organic matter composed of discarded potatoes, carrots, onions and cabbage skins, each at the same percentage (25%) by weight, according to Chellapandi *et al*. (2008), with or without a catalyst added. All specimens were deposited in 0.6-liter PET polymer recipients (reused commercial soft drink containers), which were hermetically sealed using their own lids.

For each organic substrate, five specimens were mounted with the same composition, as indicated above, varying in the presence or absence of a catalyst, forming three groups, as follows, Group A: substrate without a catalyst; Group B: substrate with 30ml of 5% w/v boric acid (H_3BO_3); and Group C: substrate with 30ml of 5% w/v sodium bicarbonate ($NaHCO_3$).

The process started at ambient temperature and tests were performed without applying any heat source, with an average temperature of ~27ºC. The anaerobic digestion process took 24 days, after which the biogas production was assessed, as well as other intermediate and final parameters of the process.

Special attention was paid to the reused commercial PET bottles, as they were chosen as biodigesters given their physical characteristics (high strength, low permeability, non-toxicity, minimum internal pressure of 1206kPa, etc). The research developed by the Group of Research and Development of Clean Energies (GIDEL, for its Spanish acronym), at Universidad Simón Bolívar, Venezuela, was conceived in the framework of the implementation of ecological science and, therefore, the performance of the reused PET bottle meets this requirement.

Valuation indicators

The indicators for the quantification and qualification of the biogas generation were: pressure, mass and composition of the biogas obtained. The obtained mass of biogas was estimated from the law of conservation of mass (Eqs. 1, 2 and 3):

$$M_{biogas} = M_f - M_{w/o\ biogas} \quad (1)$$

$$M_f = M_{probe} + M_{substrate} + M_{catalyst} + M_{biogas} \quad (2)$$

$$M_{w/o\ biogas} = M_{probe} + M_{substrate} + M_{catalyst} + M_{air} - K \quad (3)$$

where M: mass, Mf: mass at the end of the experience (with the biogas produced), Mw/o biogas: mass once the biogas is released from the bottle and this is filled with air at ambient conditions, and K: mass of air within the container of 0.666 liters.

Pressure and biogas composition are to be characterized in the next step of this research program. However, while developing the system for such characterization, the pressure was indirectly measured through the deformation of the container geometry; i.e., the volume of the container varied with the biogas production and this was measured along the experiment as an indirect indicator of the internal pressure in the container, as explained in the next section.

Variation of the container geometry

The geometry changes for each of the containers in the three groups of samples, as a function of time, were proportional to the biogas generation. These geometrical indicators were defined by three diameters and the volume of the container.

Figure 1 outlines the bottle being used as the container (similar brand names were used to guarantee similar shapes for all the containers). Three diameters, measured with caliper precision, were defined as D1, at 5cm from the top of the specimen, under the cap; D2, at the cylindrical mid-section zone; and D3, at 5cm from the base of the container.

Additionally, the volume (V) of the entire bottle was determined by dipping it into a previously calibrated container and measuring the volume of displaced water.

Diameter measurements were taken every three days, for a total of eight measurements, and volume measurements were taken every six days for a total of four measurements

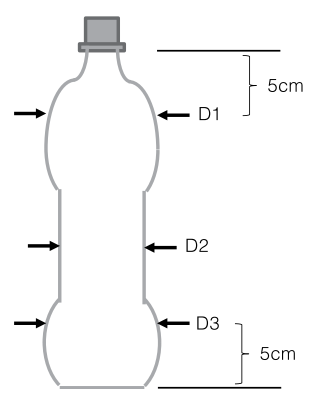

Figure 1. Schematic of the PET probe indicating diameters D1, D2 and D3.

TABLE I
AVERAGE DIAMETER 1 OF PET CONTAINERS FOR EACH SAMPLE DURING ANAEROBIC DIGESTION

Sample	Average diameter 1 (in) for each sample							
(days)	3	6	9	12	15	18	21	24
A: Substrate w/o catalyst	6.69	6.70	6.71	6.71	6.72	6.72	6.72	6.72
B: Sustrate w/boric acid	6.67	6.68	6.69	6.69	6.70	6.70	6.70	6.70
C: Substrate w/sodium bicarbonate	6.68	6.70	6.71	6.71	6.72	6.72	6.72	6.72

TABLE II
AVERAGE DIAMETER 2 OF PET CONTAINERS FOR EACH SAMPLE DURING ANAEROBIC DIGESTION

Sample	Average diameter 2 (in) for each sample							
(days)	3	6	9	12	15	18	21	24
A: Substrate w/o catalyst	6.23	6.24	6.25	6.26	6.26	6.27	6.27	6.28
B: Sustrate w/boric acid	6.18	6.19	6.23	6.25	6.25	6.26	6.26	6.26
C: Substrate w/sodium bicarbonate	6.25	6.25	6.27	6.29	6.29	6.29	6.29	6.30

TABLE III
AVERAGE DIAMETER 3 OF PET CONTAINERS FOR EACH SAMPLE DURING ANAEROBIC DIGESTION

Sample	Average diameter 3 (in) for each sample							
(days)	3	6	9	12	15	18	21	24
A: Substrate w/o catalyst	6.69	6.70	6.73	6.74	6.74	6.74	6.74	6.74
B: Sustrate w/boric acid	6.62	6.65	6.68	6.70	6.70	6.70	6.71	6.71
C: Substrate w/sodium bicarbonate	6.67	6.69	6.71	6.72	6.72	6.72	6.72	6.73

TABLE IV
MEASUREMENTS OF THE VOLUME OF PET CONTAINERS DURING BIOGAS PRODUCTION

Sample	Mean value ± standard desviation of volumen (L) for each sample			
(days)	6	12	18	24
A: Substrate w/o catalyst	624 ±5.48	632 ±4.47	642 ±4.47	646 ±5.48
B: Sustrate w/boric acid	638 ±4.47	642 ±4.47	646 ±5.48	646 ±5.48
C: Substrate w/sodium bicarbonate	650 ±7.07	650 ±7.07	660 ±0.28	660 ±4.47

TABLE V
BIOGAS MASS ESTIMATES

Sample	Mean value ± standard desviation of volumen (L) for each sample		
(days)	M_f (g)	$M_{w/o\ biogas}$ (g)	M_{biogas} (g)
A: Substrate w/o catalyst	93.76172 ±2.397124	92.5687 ±2.397763	1.19302 ±0.003958
B: Sustrate w/boric acid	116.48594 ±2.003892	115.48492 ±2.004894	1.00102 ±0.005843
C: Substrate w/sodium bicarbonate	118.93424 ±1.680919	114.88794 ±1.690142	4.04630 ±0.024999

TABLE VI
MAXIMUM DIFFERENCES FOR MEAN BIOGAS MASS PRODUCTION

	Mean mass A	Mean mass B	Mean mass C
Mean mass A	1	7.79×10^{-11}	1.03×10^{-08}
Mean mass B	-	1	1.48×10^{-09}
Mean mass C	-	-	1

throughout the entire experiment.

Measurements were tabulated and mean and variance of the data were calculated and plotted to observe the trends. The mass calculated from Eqs. 1, 2 and 3 generated a table for comparison and to compute the maximum mean significant differences between groups, based on the statistical t-test, with two distribution tails and assuming samples with different variances (heteroscedastics).

Results

Diameter measurements

Tables I, II and III summarize the results for the measurements of diameters D1, D2 and D3. Figure 2 shows the trends of average diameters for each experiment.

Volume measurements

Table IV shows the volume measurements of the PET containers during the experiments.

Biogas mass

The biogas mass production can be seen in the last column of Table V, and the comparison of mean values for the three experimental groups via statistical t-test, indicating significant differences is shown in Table VI.

It can be observed that the biogas mass with boric acid is smaller than the biogas mass without catalyst, and the latter is in turn smaller than the biogas mass with sodium bicarbonate.

Concluding Remarks

An anaerobic digestion process using organic residues and recycled PET containers was assessed. Three different groups of experiments were considered: two of them with different catalyst agents (boric acid and sodium bicarbonate) for the production of biogas, while a third one without catalyst agent, as a control experiment.

Using a singular methodology for biogas mass calculation, the experimental results pointed to:

a) The biogas bulk generation was uniform within each set of experiments for the same group, with no significant differences between the specimens of the same group, proving the repeatability of the data.

b) The biogas mass production using boric acid as catalyst was much smaller than biogas production with sodium bicarbonate as catalyst. The use of boric acid proved to be a slower agent since the biogas production was even smaller than the process without catalyst.

c) Recycling PET containers for biogas production may

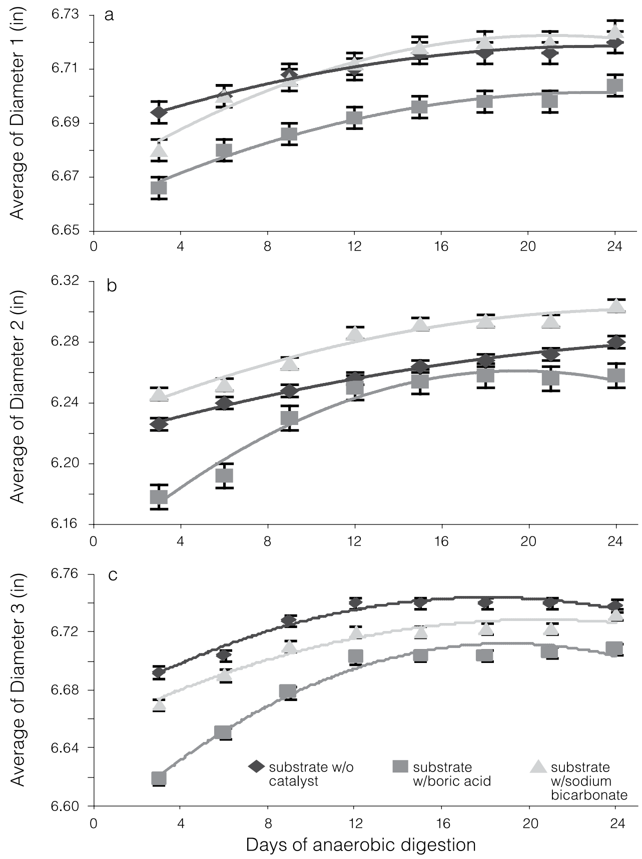

Figure 2. Average diameter (in). a: diameter 1, b: diameter 2, c: diameter 3.

become a useful and ecological procedure if these small biodigesters prove in further tests their advantages for this purpose as they did in this preliminary research.

d) For the next steps of this study, in order to improve the accuracy of the results, it is recommended to increase the sample size, review and improve the method of mass measurement and implement factorial experiments to pinpoint the contribution of each element of the substrate to the biogas generation.

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