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Biogas Production Using "Gas Endeavour" Automatic Gas Flow System †

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Abstract: In recent years, there have been growing concerns about finding alternatives to fossil fuels, and biomass could be one of them. To ensure the production of biogas as one of the alternative sources, the development of anaerobic digestion technologies for agricultural and animal waste is one of the promising directions. In this work, the process of biogas production from different types of solid substrates and microalgae was studied using an automatic gas flow measurement system. The biogas flow rate was monitored throughout the process. In order to use the digestate resulting from biogas production as a soil improver, the content of macroelements was analyzed.

Keywords: biogas; gas endeavor; biomass; anaerobic digestion; biomethane

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1. Introduction

In recent years, biogas production from biomass waste has attracted more and more interest. Biogas is one of the important components of the global concept of obtaining energy from renewable resources. The use of agricultural and animal waste for the production of energy through anaerobic digestion represents one of the most promising and sustainable alternative sources for obtaining renewable, sustainable energy. This offers a practical approach to reducing the energy deficit [1]. The rational use solves two major problems: the first—environmental, by reducing environmental pollution, and the second—energy, by obtaining biogas as a renewable source of electricity and heat [2]. To ensure biogas production as one of the "green" alternative energy sources, the development of anaerobic digestion technologies for liquid and solid agricultural waste is one of the promising directions.

Currently, a large number of technologies have been developed and applied to obtain biogas based on the use of different conditions for its production: temperature, humidity, biomass concentrations, methanogenic process over time, etc.

The solution for increasing the efficiency of biogas production from agricultural wastes should be based on the improvement of production parameters (cost reduction, efficiency improvement, etc.), equipment and technological schemes, as well as the development and implementation of new technologies [3].

Anaerobic digestion is used to produce biogas from organic waste such as sewage sludge and agricultural and industrial by-products. Recently, this technique has also been applied to microalgal biomass and residues from lipid extraction. In this process, complex organic molecules are first hydrolyzed, forming long-chain free fatty acids (LCFA) and alcohols from lipids, sugars from carbohydrates, and amino acids from proteins. The simple organic molecules are then fermented to produce volatile fatty acids (short-chain fatty acids) such as propionic, butyric, and valeric acids by acidogenesis and acetic acid, respectively, following the acetogenesis step. Finally, methane is produced from acetate and hydrogen by methanogenesis. The main products of the methanogenesis process are a biodegradable effluent, known as digestate, and biogas, which generally contains carbon dioxide and methane, with small traces of ammonia, hydrogen sulfide, and water vapor [4].

A more recent trend in anaerobic digestion is the use of a mixture of substrates to achieve higher biogas yields due to synergistic interactions between substrates, known as co-digestion. Co-digestion is the mixing of two or more than one type of residue. Co-digestion can also lead to improved anaerobic digestion [5].

Looking at the final digestate resulting from biogas production, there are studies from the literature on the possibility of using it as fertilizer. This biomass can fertilize the soil and can be used to reduce the amount of classic mineral fertilizers. Also, there were studies on the detection of changes in the content of macroelements before and after the application of digestate on different soils [6].

The aim of the present work was to study the biogas production process from different types of solid substrates and microalgae in an appropriate proportion using an automatic gas flow measuring system.

2. Materials and Methods

2.1. Biomass Composition

Different types of vegetable and animal wastes used as solid substrate were collected from local farmers in the south of the country. The microalgae Chlorella vulgaris sp. biomass was obtained from the laboratories of the National Research and Development Institute for Chemistry and Petrochemistry, dried and mixed with substrate for anaerobic digestion. Wastewater collected from the city's sewage treatment plants was used as the inoculum.

For the anaerobic digestion process, 5 samples were prepared with substrates of different compositions. Microcrystalline cellulose was used as the control sample. The useful volume of the reactor for these experiments was 400 mL, of which 150 g represented plant biomass and animal manure with a dry matter content of 10% of the total mass of each sample and 250 mL aqueous solution of inoculum. The composition of samples undergoing anaerobic digestion is shown in Table 1. The working parameters for anaerobic digestion were a 37 °C temperature for mezophilic condition, stirring speed 100 rpm, in cycles of 20 min on, 20 min off, and a process duration of 27 days.

Table 1. Biomass composition.

Experiment No.	Control (g)	Potatoes (g)	Sugar Beet (g)	Cabbage (g)	Pig Manure (g)	Dry Microalgae (g)	Liquid Digestate (Inoculum) (mL)
1	3	-	-	-	-	-	250
2	-	-	-	135	-	15	250
3	-	75	-	-	75	-	250
4	-	-	41.25	109	-	-	250
5	-	19.8	6.7	50	70	4	250

2.2. Anaerobic Digestion of Biomass

2.2.1. Automatic Gas Flow Measuring System

Experiments on the anaerobic co-digestion process of agricultural by-products and waste algal biomass were conducted using an Automatic Gas Flow Measuring System (Gas

Endeavour), BPC Instruments AB, Sweden (Figure 1). This system consisted of a sample incubation unit with a maximum of 15 glass reactors with a standard volume of 500 mL, provided with an automatic stirring/mixing system with a timer and controlled by the software control interface of the equipment. At the same time, the incubation unit allowed temperature maintenance during the anaerobic digestion process, while simultaneously acting as a thermostatic water bath.

Figure 1. Automatic gas flow measuring system used for anaerobic digestion.

2.2.2. Carbon Dioxide Absorption Unit

Another component of the equipment is the gas absorption and neutralization unit. Each digestion reactor was connected to a glass vessel containing 80 mL 3 M NaOH solution for removal of the acidic components from gas mixture resulting from the digestion process, i.e., CO_2 and H_2S.

2.2.3. Biogas Production and Monitoring

The concentrated methane stream from the absorption unit was directed to the dosing unit. This unit was equipped with 9 mL paddles, which allow a methane flow rate between 9 and 110 mL/min to be recorded. The flow obtained in the dosing unit was recorded by the software of the equipment that allows the generation of graphic data obtained for each reactor individually during the experiment.

2.2.4. Final Product Analysis

In order to use the final digestate in agriculture, inductively coupled plasma optical emission spectrometry (ICP-OES) was used for nutrient content analysis, such as phosphorus (P) and potassium (K). The elemental analysis method was performed to determine the total nitrogen (TN) content.

3. Results and Discussion

Table 1 shows the composition of the biomass subjected to anaerobic digestion for the five experiments performed in the automatic gas flow measurement system during the 27 days. Combining plant waste and animal manure in the digestion process showed a beneficial interaction resulting in increased biogas production, primarily because of the swift breakdown of plant waste and the stabilizing influence of animal manure.

Table 2 shows the maximum values for the cumulative volume of biogas for the studied experiments after 27 days. As can be seen, the best values were obtained in the case of experiment 5 (E5).

Table 2. The total volume of cumulative biogas.

	Experiment 1 (E1)	Experiment 2 (E2)	Experiment 3 (E3)	Experiment 4 (E4)	Experiment 5 (E5)
Total Volume (mL)	717	2151	1771	1642	3619

Biogas production was studied for different biomass compositions and reached the optimal ratio for E5. The elimination of some compounds from the substrate influenced the daily production of biogas. E2, loaded with cabbage and potatoes (plant waste), yielded 2151 ± 9 mL, and E4, loaded with cabbage and sugar beet, yielded 1642 ± 9 mL, while E5, loaded with potatoes, sugar beet, microalgae waste, pig manure, and cabbage (plant waste and animal manure), produced 3619 ± 8 mL of biomethane over 27 days of anaerobic digestion (Figure 2). At a consistent temperature of 37 °C and using the same amount 250 mL of inoculum, E5 yielded 68% more biogas than E2 and 120% compared to E4. This boost in gas production is likely a result of the influence achieved by co-digesting plant/food waste and animal manure in a single digester. This effect stems from the advantageous qualities of both substrates, with food waste's high biodegradability ensuring a greater availability of substrates for biogas conversion [7].

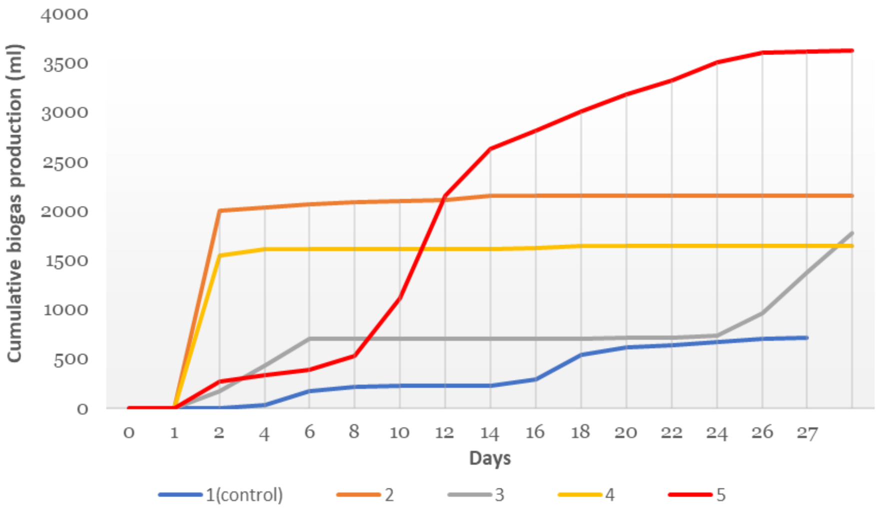

Figure 2. Comparison of the total cumulative volume of biogas for different biomass compositions.

Figure 2 describes the comparison of the total cumulative biogas volume for different biomass compositions. For E2 and E4, production increased on the first day; this rapid increase could be due to the degradation of soluble carbohydrates available in the substrate of animal origin. Then, no growth was observed, probably due to the decrease in pH and possibly due to the accumulation of volatile compounds and the degradation of complex compounds [8].

In the case of E5, a slower growth was observed in the first days; a significant increase in the volume of biogas being registered was observed on the 11th day, and then the gas production gradually increased, probably due to the gradual acclimatization of the microorganisms to the reaction medium.

After this period, there was a decrease in biogas production as the biodegradable organic matter gradually depleted. Low biogas production rates were observed after day 27, which means that anaerobic digestion was complete after this period.

The larger amount of biogas in experiments E5 and E3 may also be due to the content of the substrate of animal origin from the composition of the initial mixture. Previous studies have shown that the higher content of indigestible proteins in pig manure [9,10] can facilitate the production of bigas. This is related to the synergistic effect of co-digestion and the C/N ratio.

Figure 3 shows the daily volume of biogas flow during the anaerobic digestion.

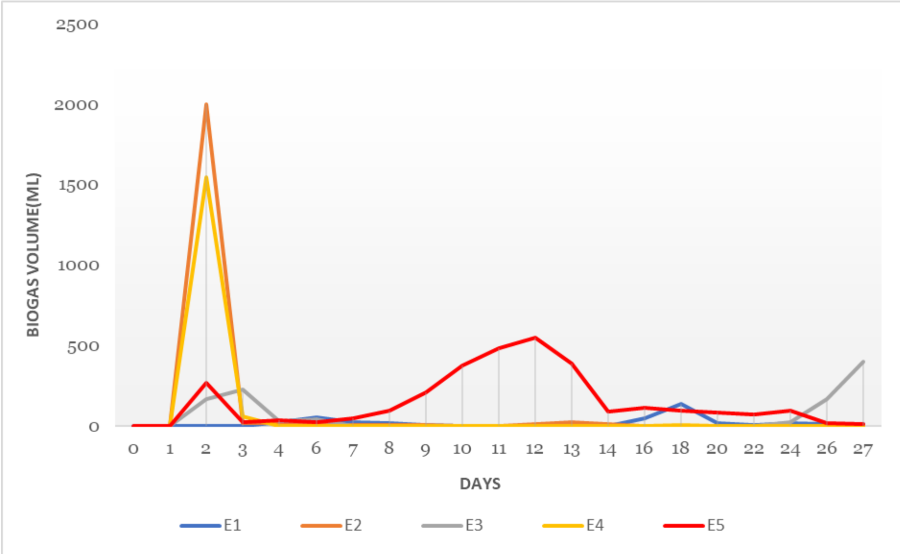

Figure 3. Daily biogas volume.

For Experiments 2 and 4, biogas generation started with a very fast evolution (first 2 days), so after those 2 days the nitrogen source was exhausted.

Experiment 5 started the methanogenesis stage after 7 days, evolved gradually for 5 days, and then had a constant evolution throughout the anaerobic digestion process. After the 13th day, there was a period of decline which was continued by a constant increase until the 25th day, and then there was a small decrease until the process stopped.

Table 3 shows the content of the selected macroelements contained in both the liquid and solid fractions for experiment 5 and experiment 1.

Table 3. The content of selected macroelements.

Macroelements, % (m/m)	E1 (Liquid)	E5 (Liquid)	E1 (Solid)	E5 (Solid)
TN	<1.19	<1.19	1.96	2.75
P	0.003	0.11	0.73	1.78
K	0.099	0.19	0.86	0.80

The analysis of the results regarding the content of macroelements showed an increase in the total nitrogen content (2.75%) and the phosphorus content (1.78%) in the solid fraction for E5, while for the liquid fraction the amount of total nitrogen was very small (<0.19%) for both samples (E5 and E1). Regarding the amount of potassium, it was approximately the same in the case of the solid samples (0.8% for E5 and 0.86% for E1).

The results regarding the content of the macroelements show that they can replace or supplement the usual soil improvers with the digestate obtained after obtaining biogas.

4. Conclusions

Biogas production is influenced by the composition of the reaction substrate. Therefore, the present study suggests that anaerobic co-digestion of plant waste and animal manure in a proper ratio could be a sustainable way to simultaneously mitigate the environmental problem and energy crisis and optimize the methanogenesis process by using the automatic gas flow measuring system. Regarding biogas production, the best results were obtained in the case of the mixture containing potatoes, sugar beet, microalgae waste, pig manure, and cabbage. Taking into account the nutrient content of the residual biomass, good results were obtained for the same experiment, with the digestate resulting from the biogas production being suitable for further use in agriculture as soil improvers.

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