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Optimization of Biomethane Production from Chicken Droppings and Pig Manure

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Abstract To meet energy needs, especially in developing countries in a situation of global energy crisis, it is necessary to extend to renewable energies, in this case biogas. One of the ways of producing this renewable energy is the co-digestion of livestock waste. The present study aims to optimize the production of methane from chicken droppings (CD) and pig manure (PM). The collection of substrates was done in a breeding center in the city of Kara. The physico-chemical characteristics of the substrates were determined. Co-digestion tests were carried out with 500 mL digesters. Anaerobic digestion was monitored for a period of 28 days at a laboratory temperature of 27 ± 2°C. Biomethane flammability tests have been carried out. The characterization of the substrates indicates that they are favorable to anaerobic digestion. The results obtained at the end of these studies reveal an average daily production of methane of 41.00 ± 19.28 mL, 25.02 ± 10.97 mL, 66.43 ± 33.43 mL and 72.86 ± 33.52 mL per 100 g of co-substrates respectively for the scenarios 100%PM, 100%CD, 1/3PM+2/3CD and 2/3PM+1/3CD. The methane production potentials of effluents gave high productivities for pig manure compared to chicken manure. The optimal methane production value is observed in the case of Co-digestion (1/3CD + 2/3PM). Then, the methane obtained is flammable from the second week of the cycle.

Keywords: *chicken droppings, pig manure, methane, flammability, co-digestion and renewable energy*

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1. Introduction

Energy is one of the most important factors in the development of a country. To meet energy needs, especially in developing countries in a situation of global energy crisis, it is necessary to extend to renewable energies, in this case biogas. Biogas is a renewable energy source. It comes from the biomethanization of organic waste. The production of biogas by biomethanation depends on the nature of the substrate [1]. In Togo, the number of the population continues to increase. Despite the strong dependence of the population on energy from wood, there is still an increased demand and consumption of energy due to the perpetual increase in population. Togo is also known for its agricultural vocation, where there is interaction between agriculture and livestock activities. For livestock products, there are consumable parts and non-consumable parts. These are known as rearing rejects or by-products. Livestock waste is qualified as polluting the environment [2]. To overcome this problem on the use of non-renewable energies and the fact that livestock waste is qualified as pollutants; means must be found to treat or transform this waste. Their transformation by biomethanization into usable energy presents itself as an interesting approach. In Togo, several livestock sectors exist, including chickens and pigs, and substrates from livestock farming can contribute to the production of biogas. However, studies already exist for the recovery of certain livestock waste in Togo (cow dung) but this is not the case for chicken droppings or pig manure. The general problem of this study is: "how is the production of biogas from chicken droppings and pig manure by biomethanation characterized? ". The present work aims to contribute to the valorization of these substrates in energy. Anaerobic digestion, or methanization, is a fermentation process of degradation of organic matter which is accompanied by the production of biogas, a gaseous mixture of CH_4 and CO_2 [3]. Unlike other forms of renewable energy, biogas technology offers many benefits in terms of waste management, energy, health and the environment [4]. In addition, the use of biogas technology increases the share of renewable energy in the energy mix and sustainable development. Mixed treatment of organic substrates, or co-digestion, improves the technical operation and performance of facilities while increasing economic profitability through the additional recovery of energy and/or the service linked to the treatment of co-products [5]. In Togo, methanisation on a laboratory scale has been developed but not all substrates have yet been tested. The treatment by anaerobic digestion of pig slurry and poultry droppings is less or almost not studied in Togo. The new directions consist of studying on a laboratory scale and validating on a pre-industrial unit, the co-digestion of slurry mixed with poultry (chicken) droppings. Indeed, if the anaerobic digestion of pig slurry has been the subject of studies [2], few studies have focused on the performance of combinations with fermentable co-substrates. Thus, the objective is to evaluate the performance of methane production by the anaerobic co-digestion of chicken droppings and pig manure.

2. Experimental Work

2.1. Sampling of Substrates

Pig manure is collected in a pigsty and chicken droppings in a poultry farm in the town of Kara. The material required for the collection of the substrates was: A latex glove and a cylindrical aluminum box of 750 mL in volume. The latex glove made it easier to collect and handle the substrates by hand. The aluminum box favored the conservation of the substrates until their use the same day.

2.2. Physico-chemical Characteristics of Substrates

Determination of moisture content, dry and volatile matter content Two types of substrate were mixed: chicken droppings and pig manure. Before the launch of the experiment, the dry matter (DM) and volatile dry matter (DSM) contents of the substrates are determined according to standard methods. The moisture content and the dry matter content of the substrates are determined on an initial mass of approximately 10 g. This method consisted of placing the samples in an oven at 100°C (± 3°C) for 6 hours [5]. The results obtained made it possible to calculate the quantities of co-substrates to be introduced into the digesters. Other parameters influencing biogas production were evaluated. These are pH and C/N ratio by appropriate methods. After mixing the substrates and distilled water, the vials were sealed.

2.2.1. pH Determination

The pH of the co-substrates was determined on a suspension obtained from a 200 g sample in 500 mL of distilled water using a Storius PT-10 pH meter.

2.2.2. Nitrogen Kjeldahl (NTK)

The Kjeldahl nitrogen was determined by the Kjeldahl method according to formula 1.

$$\mathrm{NTK} = \frac{2\left(\mathrm{V}_1 - \mathrm{V}_0\right)\mathrm{x\ C\ x1000x14}}{\mathrm{V}} \qquad (1)$$

With: C = the concentration in mol/L of the sulfuric acid solution (0.05M)
V_1 = the volume of sulfuric acid used to dose the sample,
V_o = the volume of sulfuric acid used for the determination of the blank test
V = the sample volume.

2.2.3. Total Organic Carbon and Organic Matter %MO

The technique used is that of Walkley and Black [6]. The percentage of TOC measured in the substrates was determined by Formula 2.

$$\%C_{org} = \left[X_1 + \left(10 - X_2\right)\right]0,003\frac{100}{77}\times\frac{100}{m} \qquad (2)$$

m: mass of CD or PM (g)
X_1: Volume of dichromate used for the control (mL)
X_2: Volume of dichromate used for the sample (mL).

2.3. Co-digestion Scenarios

It was necessary to assess the methane production potential of each type of substrate and also of their co-digestion. Thus, four scenarios were formulated:

Scenario 1: feeding the digester with 100%CD
Scenario 2: feeding the digester only with 100%PM
Scenario 3: feeding the digester with 1/3PM + 2/3CD
Scenario 4: feeding the digester with 2/3PM+1/3CD
With CD: chicken droppings; PM: pig manure

Tests conducted in a mesophilic regime (37°C) consisted of monitoring the performance of methane production by these residues [7]. Each scenario is assigned its own wording. On a formulation, the corresponding volume of water, the mass of chicken droppings and the mass of pig manure are mentioned (Table 1).

Table 1. Characteristics of the scenarios

	Scenarios			
	1	2	3	4
Water (mL)	400	400	400	400
Chichen droppings (g/MS)	0	100	67	33
Pig manure (g/MS)	100	0	33	67

2.4. Experimental Apparatus

The experimental device intended to carry out the anaerobic digestion of CD, PM and the anaerobic Co-digestion of CD and PM, consists of four polyethylene cans of 5 L volume, four digesters of five hundred milliliters (500 mL) and four one hundred milliliter (100 mL) test tubes. Two holes (8 mm) at the level of the lid and the base allow the passage of a PVC pipe of 8 mm in diameter connected to a peristaltic pump in order to allow the recirculation of the methane from the digester towards the container filled with soda water (pH = 12). Once in the container, the methane expels the water from the container which falls into the test tube. Each digester is associated with an electric thermometer to control the variation of the internal temperature. This volume of water displaced is equivalent to the volume of methane produced (Figure 1).

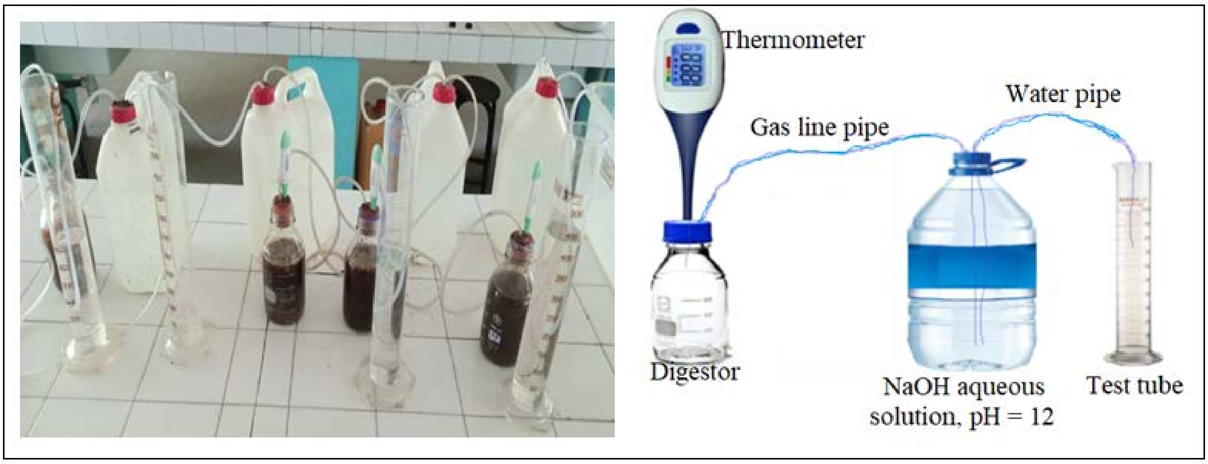

Figure 1. Experimental device

2.5. Monitoring of Methane Production

For each test, production monitoring is carried out per day and at a fixed time (at 7 am). Monitoring consisted of recording the quantity of methane for each scenario in the daily production sheet. The results on the daily production sheet allowed the assessment and interpretation of the methane production, in particular the daily evolution and the evolution of the cumulative production over the 28 days of production, then the flammability of the methane produced. The tests are carried out in digesters with a capacity of 500 mL. Hermetically sealed, the fermenters are maintained at laboratory temperature (27°C). Each digester is connected to a water column allowing measurement of the volume of methane produced over time. The measuring column guard liquid is a basic solution (pH=12) in order to dissolve the CO_2 as much as possible.

3. Results and Discussions

3.1. Characteristics of the Substrates

The physico-chemical characteristics of the substrates are recorded in Table 2.

During the study, the dry matter content of chicken droppings was 93.45 ± 0.01%. This result is similar to that of Members et al. (2000), according to which Chichen droppings have a high dry matter content of at least 25%. The dry matter content of pig manure is 86.71 ± 0.01%. The moisture content is 6.55 ± 0.01%. This water content is low compared to that of pig manure which is 13.29%. This difference would be partly related to the daily washing water of the pigsty. The higher DM content of hen droppings can be explained by the fact that they are stored outside the poultry house or by their exposure to the open air. A similar study on the moisture content of poultry droppings (laying hens of the Hy-line breed) shows a value of 41.50% in dry matter [8].

Chicken droppings have a basic pH (pH = 8.01) as does pig manure (pH = 7.6) according to the study. This result is similar to that of Sadak et al. (2012) on chicken droppings which are basic in nature around pH=8.70 [9] and that of Castaing et al. (2002) on pig manure which has a pH around 7.5 [10].

Chicken droppings have 40.6 ± 0.20% DM in organic carbon. This result is high compared to the range of values obtained by Aubert and Gadis (2005) which is between 19.20% DM to 25.60% DM for poultry droppings [11]. This difference would be related to the fact that the droppings have more organic matter than mineral matter because of the rapid digestion of food for poultry [12]. As for pig manure, the carbon content is 37.8 ± 0.59%. This result is similar to that obtained by [10].

The rate of organic matter found is 58.54 ± 0.01%/DM for chicken droppings and 82.52 ± 0.003%/DM for pig manure. Compared to purebred laying hen droppings, this rate for local-bred hen droppings is low. The organic matter rate for laying hen droppings is 74.50% organic matter per dry matter. This value results from the composition of the food of laying hens [8]. By way of comparison with other species, compared to pig manure which has 82.52 ± 0.03% organic matter in relation to dry matter, that of hen droppings is low. This result is similar to that of [13] for which chicken droppings have an organic matter content of 49.91% against 78% for pig manure.

Chicken droppings have a C/N ratio = 19.00 (C= 40.60% DM and N = 2.14% DM). The high nitrogen content of chicken droppings is due to the fact that poultry manure consists of faeces and urine rich in nitrogen [5,14]. This C/N ratio of chicken droppings is low compared to the C/N ratio of pig manure which is 27 (C=37.08% DM and N=1.38% DM). This result is comparable to that of the work of Razafinandrasana who found that the C/N ratio of chicken droppings equal to 9.04 (C=29.02% DM and N=3.21% DM) is low compared to that of pig manure which is around 26 to 29 [13]. Depending on the magnitude of this C/N ratio, chicken droppings are less favorable in biomethanation compared to pig manure.

Table 2. Physico-chemical characteristics of chicken droppings and pig manure

Substrates	%DM	%OM	%TOC	%NTK	C/N	%H
Pig manure	86.71± 0.01	82.52± 0.03	37.8± 0.59	1.38± 0.01	27.00 ± 0.02	13.29± 0.01
Chichen droppings	93.45± 0.01	58.54± 0.01	40.6± 0.20	2.14± 0.05	19.00 ± 0.12	6.55± 0.01

3.2. Evaluation of Methane Production

The methane production of each substrate is representative of its level of biodegradability under anaerobic conditions [7] (Figure 2). For 100 g of substrates, pig manure has an average production of 41.00 ± 19.28 mL/d of methane against 25.02 ± 10.97 mL/d for chicken droppings.

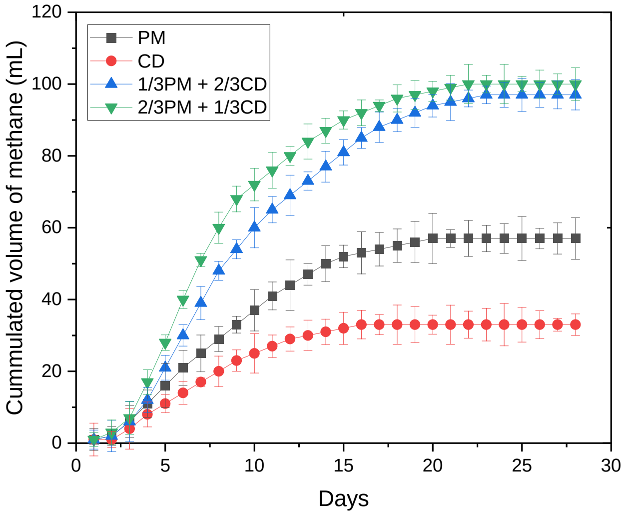

Figure 2. Cumulative biogas production of the different scenarios

The study of the biomethanation of chicken droppings and pig manure shows the existence of a daily production of methane. There is a low production the first five days, against a maximum production observed on the 22nd day of the cycle. These irregular daily productions are explained by the fact that there is a variation in the living condition of the bacteria during the biomethanation. [15] The results on the general trend of the evolution of the cumulative production of methane during the study are similar to that found by [16] during their studies on the energy recovery of biomass.

Pig manure has a higher productivity compared to chicken manure. This behavior is to be attributed to a biochemical composition rich in biodegradable compounds [17]. The addition to slurry, under controlled conditions, of chicken droppings with a high dry matter content and presenting a methane production of 72.86 ± 33.52 m^3/d, is a means of improving treatment performance. The addition of droppings to slurry allows a significant increase in the dry matter (DM) of the effluent. The addition of chicken droppings to slurry results directly in an increase in methane production which reflects the level of biodegradation of the material within the anaerobic digester. In the slurry phase alone, the production of methane is 41.00 ± 19.28 mL/d. The best methane production is obtained for the scenario in which the quantity of chicken droppings is higher. These results demonstrate the interest of Co-digestion for the gain in methane produced, a source of renewable energy.

3.3. Flammability Test

For the methane fermentation of the co-substrates (pig manure and hen droppings), the biomethane obtained is flammable (Figure 3) from the 15th day of the cycle. This result is similar to that of [13] who observed that biomethane from chicken droppings is flammable from the 13th day of the cycle.

Figure 3. Methane flammability test

3.4. Temperature Evolution

The production of methane is directly dependent on temperature. A mesophilic phase was maintained between 35 and 37°C to obtain optimal activity of methanogenic bacteria converting acetates into methane (Figure 4). High temperatures above 37°C increase reaction rates and promote the production of CO_2 and H_2O instead of methane [9].

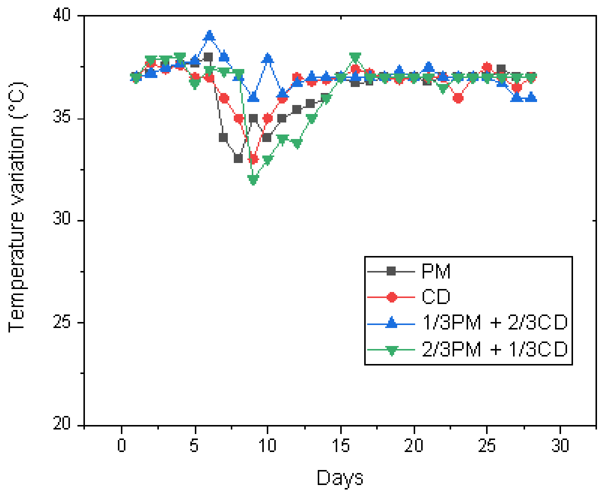

Figure 4. Temperature variation

4. Conclusion

The objective of this work is to optimize the production of methane from chicken droppings (CD) and pig manure (PM). The characterization of the substrates indicates that they are favorable to anaerobic digestion. The results obtained at the end of this study reveal an average daily production of methane of 41.00 ± 19.28 mL, 25.02 ± 10.97 mL, 66.43 ± 33.42 mL and 72.86 ± 33.52 mL per 100 g of co-substrates respectively for the scenarios 100%PM, 100%CD, 1/3PM+2/3CD and 2/3PM+1/3CD. The methane production potentials of effluents gave high productivities for pig manure compared to chicken manure. The optimal methane production value is observed in the case of Co-digestion (2/3PM + 1/3CD). The methane obtained is flammable from the second week of the cycle.

The co-digestion of pig slurry and hen droppings shows, in view of the results of this experiment, particularly encouraging prospects. The methanogenic potential tests specified the good biodegradability of these livestock effluents. These tests also reveal the interest of combining pig manure with a high dryness substrate (chicken droppings), making it possible to significantly increase the organic load introduced with the addition of a small quantity of waste. Experimental trials concerning the association of slurry with chicken droppings provide technical data on the operating methods and the interest of co-digestion. The results obtained during this experimental work are encouraging and show the interest of continuing this work in order to develop scientific and technical references for the application of potential scenarios to other issues.

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