

A Biogas Production Model from the Combination of Pig Manure and Cow Dung in N'Zérékoré City, Republic of Guinea

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Abstract

This present research work focuses on the valorization of pig droppings for production of biogas in mono digestion and co-digestion with proportions of cow dung from the urban commune of N'Zérékoré. It was carried out in December 2020 in the Physics laboratory of the University of N'Zérékoré. The anaerobic digestion process took 25 days in an almost constant ambient temperature of 25°C. Five digesters were loaded on 12/06/2020, two of which with 1 kg of pig dung and 1 kg of cow dung both in mono-digestion. The 3 other digesters in co-digestion with different proportions of pig manure and cow dung. The substrate in each digester is diluted in 2 liters of water, with a proportion of (1/2). The main results obtained are: 1) the evolution of the temperature and pH during digestion process, 2) the average biogas productions 0.61 liters for (D1); 1.20 liter for (D2); 1.65 liter for (D3); 1.51 liter for (D4) and 1.31 liter for (D5). The cumulative amounts of biogas are respectively: D1 (7.95 liters), D2 (15.60 liters), D3 (21.50 liters), D4 (19.65 liters) and D5 (17.05 liters). The total cumulative production is 81.75 liters at the end of the process. The originality of this research work is that the proposed model examines the relation between the daily biogas production and the variation of temperature, pH and pressure. The combustibility test showed the biogas produced during the first week was no combustible (contains less than 50% methane). Combustion started from the biogas produced from the 15th day and it is from the 20th day that a significant amount of stable yellow/blue flame was observed. The results of this study show the combination of pig manure and cow dung presents advantages for optimal biogas production.

Keywords

Production, Experimental, Model, Pig Manure, Cow Dung, Biogas, N'Zérékoré, Republic of Guinea

1. Introduction

Since the beginning of the industrial development, human activities have contributed considerably to the increase in the concentration of Greenhouse Gases (GHG) in the atmosphere. The breeding sector is one of the activities that have a strong impact on the natural environment, with the emission of the three main GHGs (CO_2 , CH_4 and N_2O). CH_4 represents nearly 44% of these emissions [1] [2].

In 2011, the European Union issued a directive to reduce GHGs from 80% to 95% by 2050 in order to limit global temperature rise to a maximum of 2°C . To achieve this objective, current fossil energy vectors must be replaced by renewable energies, such as biogas [3] [4]. Biogas is a flammable gas produced by the anaerobic digestion of animal, plant, human, industrial and municipal waste. It is mainly composed of methane (50% - 70%), carbon dioxide (20% - 40%) and traces of other gases (Nitrogen, Hydrogen, Ammonia, Hydrogen sulfide, etc.) [5]. The calorific value of biogas varies between 485 and 679 kWh/m^3 , its combustion temperature is between 800°C and 1100°C [6]. In addition to waste treatment and reducing fossil fuel consumption, biomethanization has additional benefits for households practicing agriculture and breeding. This is particularly the case in many rural communities in the Republic of Guinea [7]-[9]. Valuation of these animal droppings could be considered as an economical and ecological solution [1]. Environmental, cultural and socio-economic conditions favor pig breeding in Forest Guinea and in particular in the urban commune of N'Zérékoré. This breeding produces a large quantity of droppings and slurry every year, whose valuation remains a major problem [10]. Assessment of the energy potential of pig dung for the production of biogas in the urban commune of N'Zérékoré in Guinea has been recently done [11]. The combination of several organic materials (co-digestion) for the production of biogas is a technique favorable to microbial flora. The physicochemical parameters of methanizable waste have an influence on the yield and composition of biogas [12]. Assessment of the effect of mixing pig and cow dung on biogas yield is performed in [13].

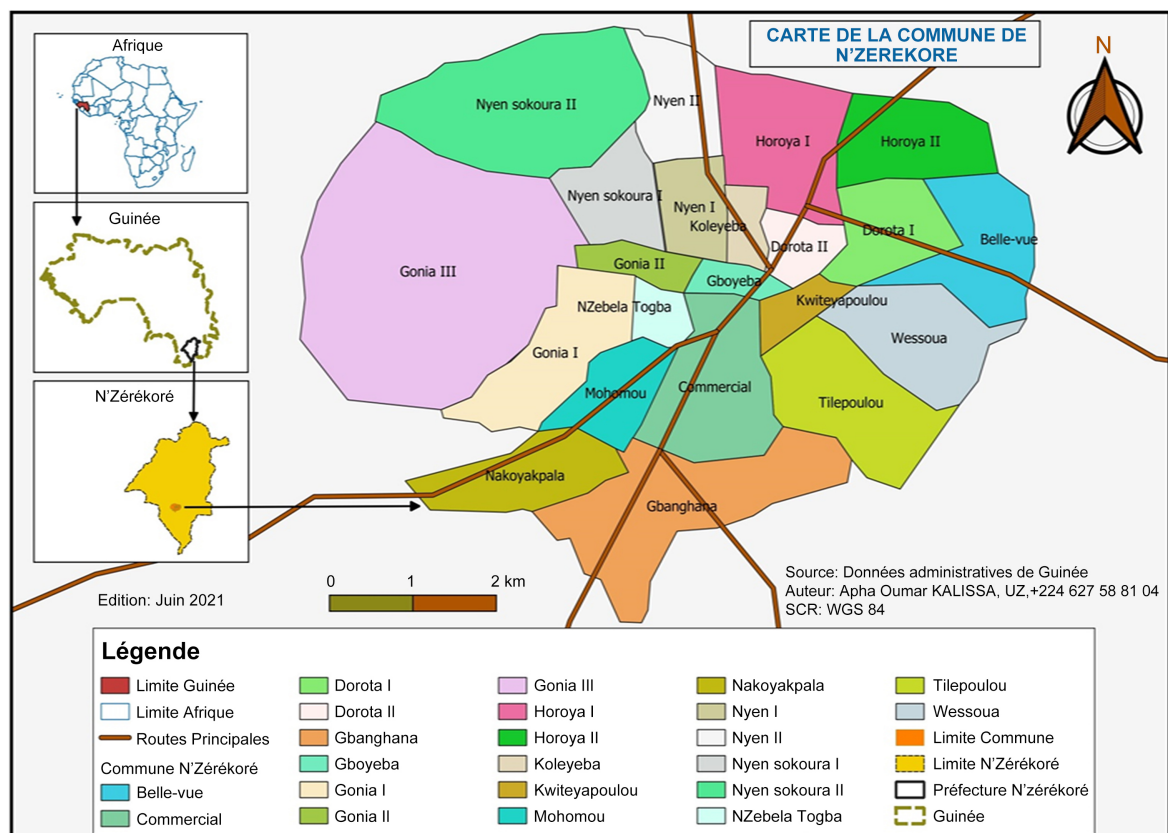
The aim of this paper is to develop a model of biogas production from pig manure in mono and co-digestion with cow dung for the urban commune of N'Zérékoré. To achieve this objective we proceeded: 1) to the design of experimental biogas production devices (biodigesters and accessories), 2) to the substrates preparation, 3) to the loading of the biodigesters with substrate, 4) and to the monitoring of the parameters (pH, pressure, temperature, daily and cumulative production) and finally, to carry out the combustion test of the gas produced by each type of substrate. This paper is organized as follows. After the introduction

section above, the Materials and Methods section is presented in which a description of the study zone is first made and the experimental method and devices allowing to produce biogas is presented. At the end the Results and Discussion Section is presented.

2. Materials

2.1. Study Area

The Prefecture of N'zérékoré is one of the 33 prefectures of Guinea. It is the largest city in Forestry Guinea, a region in the southeast of the Republic of Guinea. The city is also the capital Forest region. It is located between 7°32 and 8°22 north latitude and 9°04 west longitude and extends over 47.3 km². The distance to neighboring prefectures is 39 km for N'Zérékoré-Lola, 62 km for N'Zérékoré-Yomou, 125 km for N'Zérékoré-Beyla, 135 km for N'Zérékoré-Macenta. Nzérékoré is at an elevation of 480 m and its relief is rugged. The plateau is dominated by hills that are sometimes gneissic (Gonia) and sometimes quartz (Gboyéba). The city has three important mountains: Götö (450 m), Hononye and Kwéléyé (350 m). Sheep breeding, goats and pigs is practiced throughout the commune. The pig herd is the largest in all areas of the N'Zérékoré. Cattle are imported from neighboring communes intended directly for butchery. The Map of the urban commune of N'Zérékoré is in **Figure 1**.



2.2. Tools and Materials

To carry out this research, we used the following materials and equipment: plastic bottles, plastic flasks, cooler, gloves, graduated containers, electronic balance, analytical balance, valves, flexible pipes, clamps, liquid glue, Teflon, pH meter and temperature sensor. The physicochemical parameters of pig manure from N'Zérékoré are on average: humidity (53.83%); dry matter (44.26%); organic matter (81.39%); density (650.36%); Carbon (47.20%); Nitrogen (1.8%) and the ratio between Carbon and Nitrogen (26.22). For cow dung: humidity (82%); dry matter (22%); organic matter (52%); density (593.28%); Carbon (30.28%); Nitrogen (1.66%) and the ratio between Carbon and Nitrogen (18.27) [11] [14].

3. Methods

3.1. Substrates Preparation

The experiment was carried out at the Physics laboratory of the University of N'Zérékoré from 4 to 25/12/2020. Loading of experimental digesters with substrates began on 06/12/2020. The loading of the experimental digesters with the substrates began on 06/12/2020, the preparation of which is done as follows.

The substrate of pig manure and cow dung were each diluted in 2 liters of water in a ratio of (1/2) before being mixed in varying proportions and putting them in the different digesters as indicated in **Table 1**.

Table 1. Proportions for the different digesters.

Mixture proportion in %*	Mixture proportion in mass	Digesters	Digestion type
100% pigmanure + 0% cowdung	1 kg pig manure + 0 g cow dung	D1	Mono-digestion
75% pig manure, 25% cow dung	750 g pig manure + 250 g cow dung	D2	Co-digestion
50% pig manure, 50% cow dung	500 g pig manure + 500 g cow dung	D3	Co-digestion
25% pig manure, 75% cow dung	250 g pig manure + 750 g cow dung	D4	Co-digestion
0% pig manure, 100% cow dung	0 g pig manure + 1 kg cow dung	D5	Mono-digestion

3.2. Experimental Devices and Set Up

For the design of the digester (D), we used a plastic bottle of 4.5 liters and 124 g

empty mass, two others of the same volume, one of which is considered as a gasometer filled with water and the other empty to collect the water which is emptied from the gasometer under the pressure of the biogas produced. They are graduated in centiliter using graph paper in order to quantify the gas produced. The same device was made for the different types of substrates (**Figure 2**).

3.2.1. pH Measurement during Biogas Production Process

The hydrogen potential (pH) of the solutions was measured using a Consort brand pH meter equipped with a combined Ag/AgCl glass electrode. Calibration is carried out using pH buffer solutions.

3.2.2. Monitoring Temperature Variation in Digesters during Biogas Production Process

Monitoring of temperature variation in the different fermenters was carried out by a temperature sensor coupled to a millimeter.

3.2.3. Measurement of Daily and Cumulative Biogas Production

The daily and cumulative biogas production of each type of substrate was measured on the gasometer graduation (**Figure 2**).

3.2.4. Biogas Pressure Computing during Production Process

For a constant volume of the gasometer, increased pressure was a result of increased volume of biogas generated. The pressure can therefore be calculated by the relation between the pressure and the volume of an ideal gas.



Figure 2. Experimental devices.

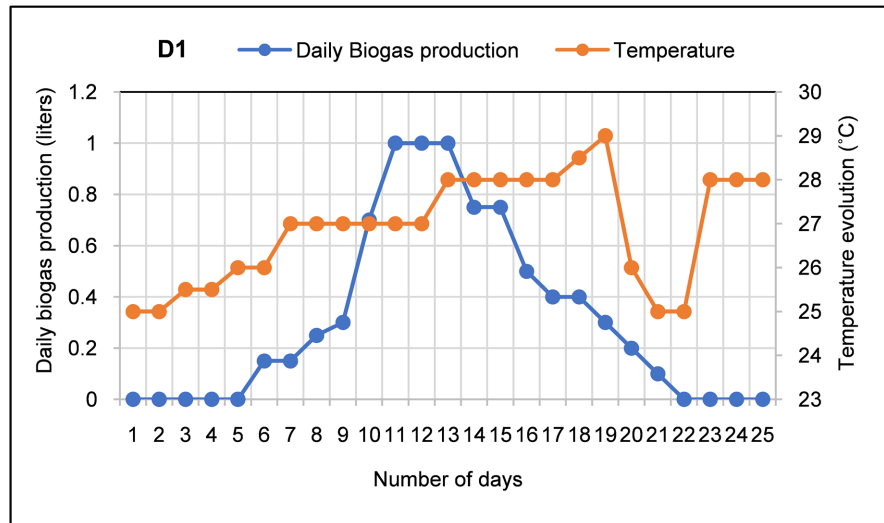
4. Results and Discussions

In this section we will first show the results of the daily biogas production, daily temperature and pH evolution in each digester. Secondly the cumulative biogas production and pressure evolution is presented before performing the combustion test of the biogas produced by each type of substrate.

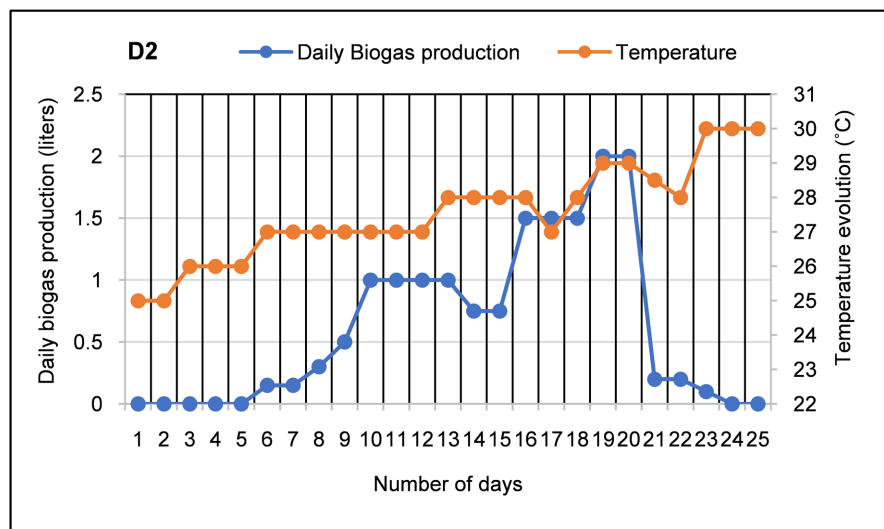
4.1. Daily Biogas Production and Temperature Evolution

The daily biogas production and temperature evolution in the five digesters are illustrated in **Figure 3**. It shows the biogas production did not start on the same day. After loading the digesters on 06/12/2020, we recorded the first production on the 4th day in digesters D1, D2 and D3 (**Figures 3(a)-(c)**) and the 2nd day in digesters D4 and D5 (**Figure 3(d), Figure 3(e)**). The quantities are respectively: 0.15 liters for both (D1 and D2); 0.25 liters for (D3); 0.5 liter for (D4) and 1 liter for (D5). During the 25 days of digestion, the largest quantity of biogas was recorded on the 15th day in the digesters (D3 and D4) with a value of 2 liters (**Figure 3(c), Figure 3(d)**). The same value was recorded on the 19th day in digester D2 (**Figure 3(b)**). The second largest value of biogas produced is 1.5 liters, recorded on the 8th day in digester D5 (**Figure 3(e)**). The smallest value 1 liter was recorded on the 11th day in digester D1 (**Figure 3(a)**). The daily average biogas production values are respectively: 0.32 liters for (D1); 0.62 liter for (D2); 0.86 liter for (D3); 0.79 for D4 and 0.68 liter for D5. It appears from these results the substrates in co-digestion with a high cow dung rate in (D3 and D4) remain the most productive. These results are in agreement with other research results [15]-[17]. The temperature in the digesters D1, D3 and D4 varied from 25°C to 29°C (**Figure 3(a), Figure 3(c), Figure 3(d)**). It varied from 25°C to 30°C in digesters D2 and D5 (**Figures 3(b)-(e)**). The average temperature value in the digesters are respectively 26.9°C for D1, 27.54°C for D2, 27.64°C for D3, 27.9°C for D4 and 28.73 for D5. These results show the average temperatures in the different digesters are relatively the same, with the highest value in the digester (D5) corresponding to 28.73°C, which contains 100% BV. This is one of the reasons that justifies the co-digestion of cow dung with other substrates for optimal biogas production [18]-[21].

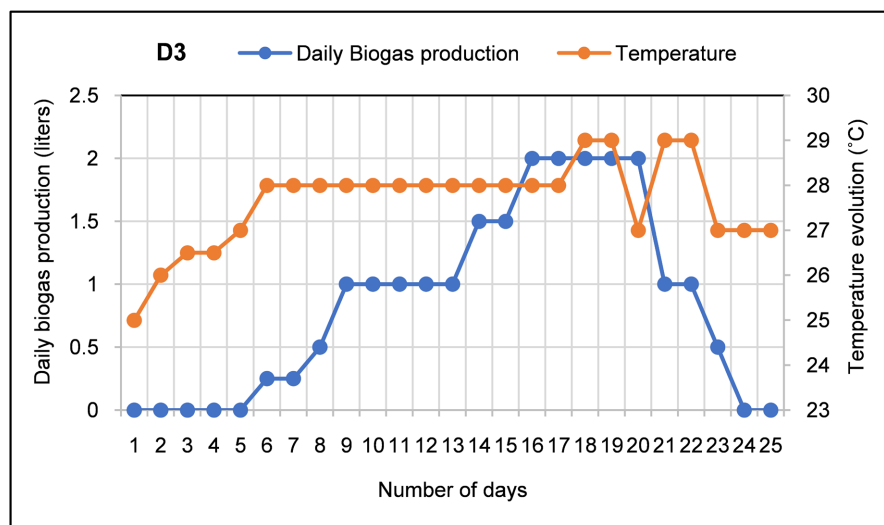
Examining the curves of daily biogas production and temperature evolution, for digester D1 we remarked from the start of biogas production (4th day) to 14th day an inverse relation between biogas production and temperature. In fact, each increase in biogas production over a day interval corresponds to a stabilization (plateau) of the temperature over the same interval (**Figure 3(a)**) while a stabilization (plateau) in biogas production over a day interval leads to an increase in temperature. From 15th day this trend is observed. For digester D3 a long period of temperature stabilization (plateau) is observed (from 6th to the 17th day) (**Figure 3(c)**) while biogas production increases and reaches its maximum value (**Figure 3(c)**). From **Figure 3**, it can be concluded the substrate in Digester D3 is the best mixture of pig manure and cow dung for optimal biogas production.



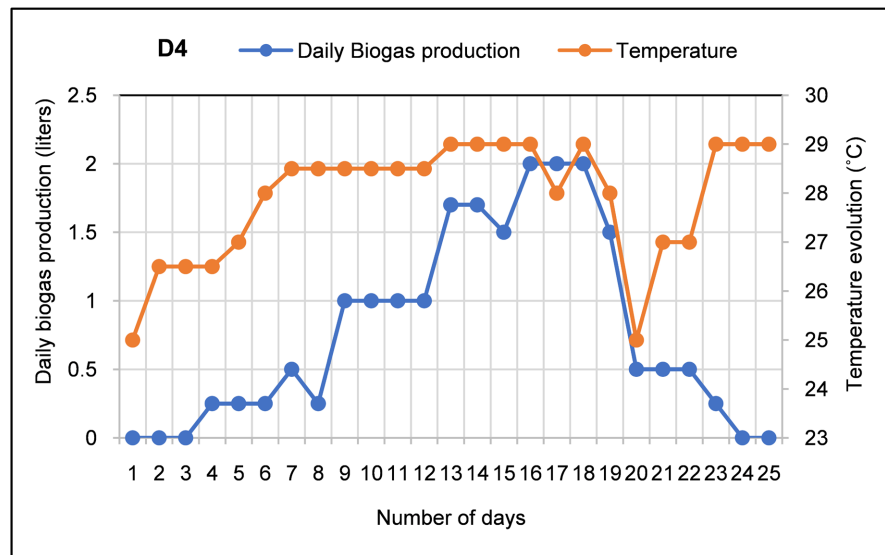
(a)



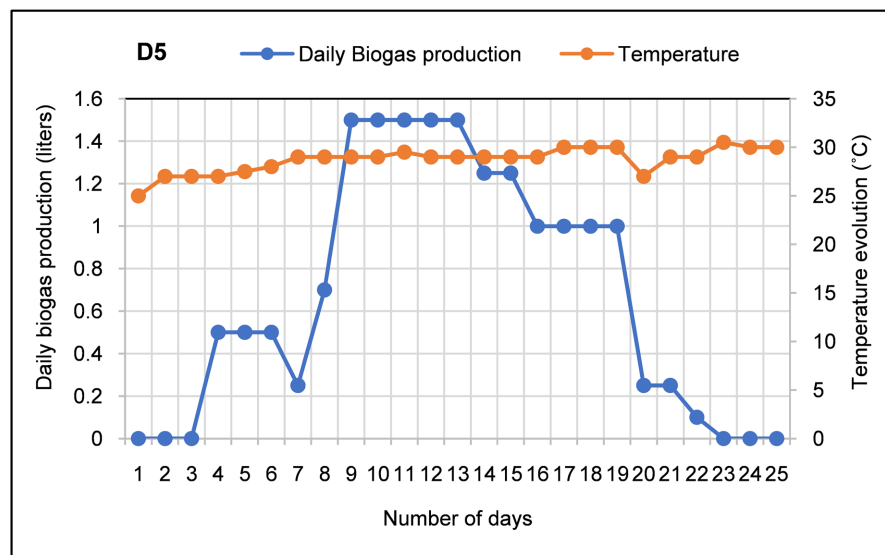
(b)



(c)



(d)



(e)

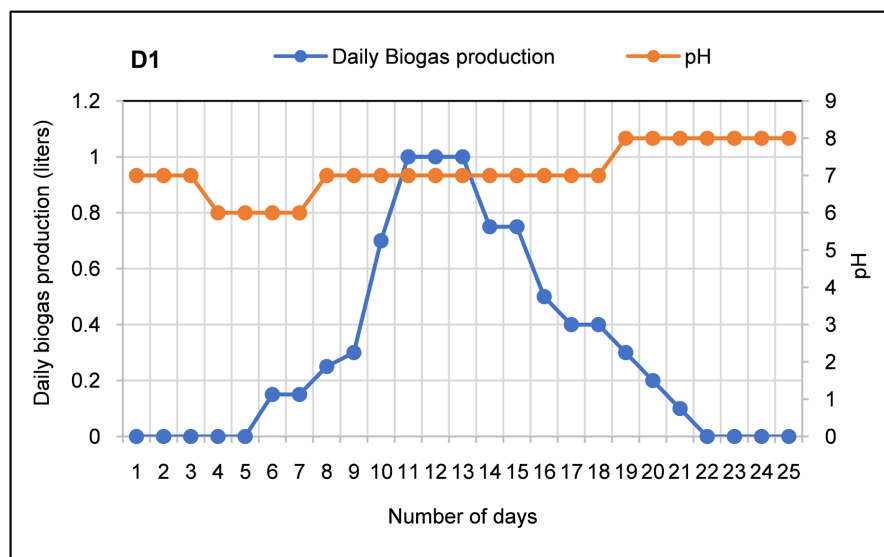
Figure 3. Daily Biogas production and temperature evolution in the digesters. (a) Digester D1, (b) digester D2, (c) digester D3, (d) digester D4, (e) digester D5 Experimental devices.

4.2. Daily Biogas Production and pH Evolution

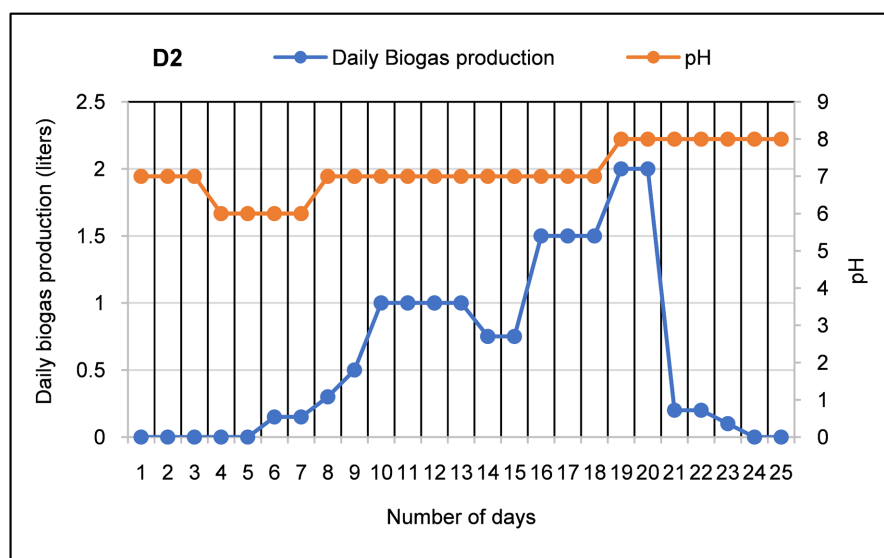
The pH variation curves of the substrates is illustrated in **Figure 4**. The pH variation curves of the substrates (**Figures 4(a)-(e)**) show that, during the digestion process, the pH varied from 5 to 8 in the five (5) digesters, with averages of 7.12 for the substrates of digesters (D1, D2 and D3) and 7.28 for the substrates digesters (D4 and D5). These average pH values are relatively similar and correspond to the neutral medium, which is favorable to the development of micro-organisms for an optimal production of biogas.

During the 25 digestion days, three phases of pH evolution were observed for each type of substrate: an acidic phase (pH around 6) until the 7th day for all the

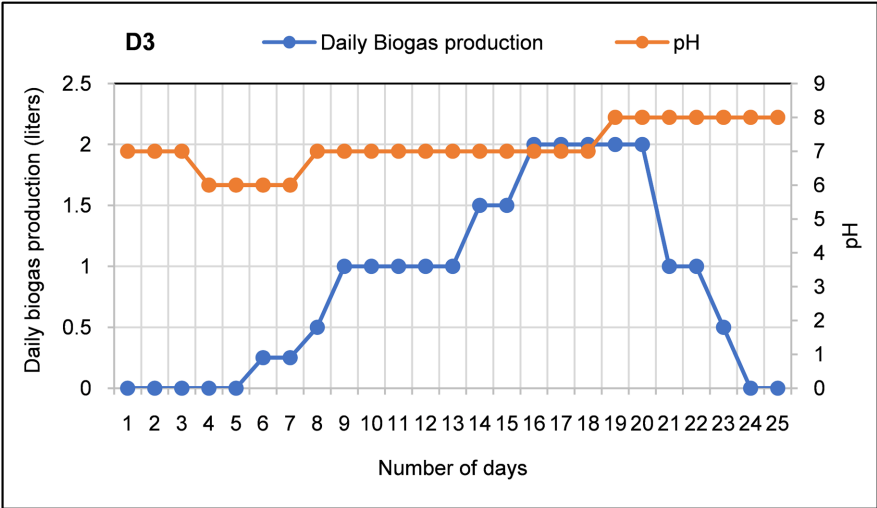
digesters (**Figures 4(a)-(e)**); a neutral phase (pH around 7) from the 8th to the 18th day for digesters D1, D2 and D3 (**Figures 4(a)-(c)**) and from 8th to 15th for digesters D4 and D5 (**Figure 4(d), Figure 4(e)**); une phase basique (pH autour de 8) du 18^{eme} au 25^{eme} jour pour les digesteurs D1, D2 et D3 (**Figures 4(a)-(c)**) et 15^{eme} au 25^{eme} pour les digesteurs D4 et D5 (**Figure 4(d), Figure 4(e)**). A basic phase (pH around 8) from the 18th to the 25th day for digesters D1, D2 and D3 (**Figures 4(a)-(c)**) and from 15th to 25th for digesters D4 and D5 (**Figure 4(d), Figure 4(e)**). It should be remembered the variation in pH is one of the indices for appreciation of biogas production in an anaerobic medium. The pH value for optimal biomethanization is around neutral (6.8 - 7.5) [2]. This demonstrates the pH values recorded during this study remain favorable to biomethanization bacteria.



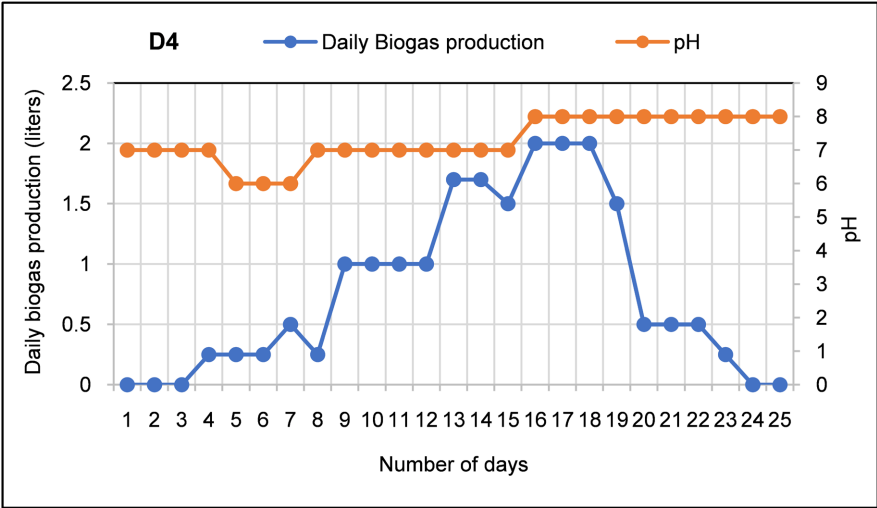
(a)



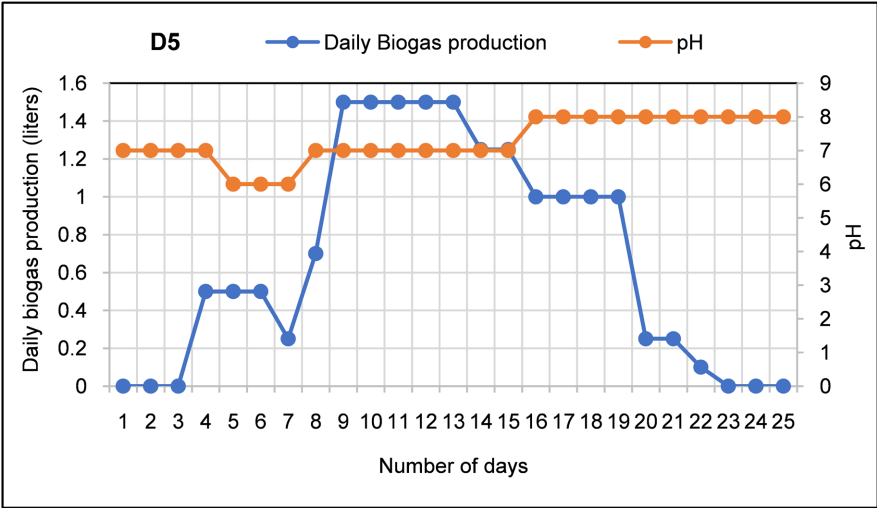
(b)



(c)



(d)



(e)

Figure 4. Daily Biogas production and pH evolution in the digesters. (a) Digester D1, (b) digester D2, (c) digester D3, (d) digester D4, (e) digester D5.

4.3. Cumulative Biogas Production

The cumulative biogas production profiles are illustrated by the curves in **Figure 5**. The curves of cumulative biogas production of the five types of substrates are all characterized by low biogas production during the first week of digestion (latency phases), then an acceleration in production was observed from 8th to 19th day (exponential phase), then a slowdown of production during the last week of digestion (bearing phase) [22] [23]. The duration of these different phases depends on the nature of the substrate [24] [25]. *Latency phase*: is the first phase (substrate liquefaction period). It corresponds to the progress of hydrolysis, acidogenesis and acetogenesis. In the present study, it lasted: 7 days for substrates in D1 and D2, with a production of 0.15 liters each of them, and 6 days for other substrates, including 0.25 liters in D3 and D4 and 0.50 liters in D5. *Exponential phase*: is the second phase, which corresponds to methanogenesis. It lasted: 12 days (from 8th to 20th day) for the substrate in D1; 14 days (from 8th to 22nd day) for the substrate in D2; 16 days (from 6th to 22nd) for the substrate in D3 and 20 days (from 4th to 22nd day) for the substrates in digesters D4 and D5. *Bearing phase*: is the third phase, it corresponds to a very low or stopping of the biogas production under the effect of substrate depletion. It starts respectively from 21st for the substrate in D1 and from the 23rd day for D2, D3, D4 and D5.

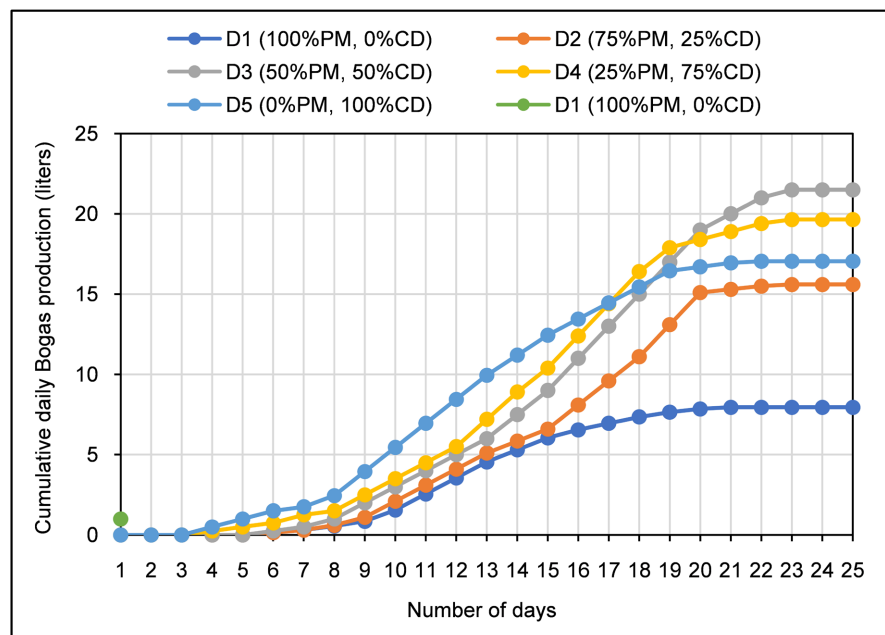


Figure 5. Cumulative biogas production profiles.

The diagrams in **Figure 6** show the cumulative biogas production during the 25 days of digestion for the substrates of the five digesters.

The cumulative production of biogas from pig manure and cow dung substrates in the proportions indicated in **Table 1** are: D1 (7.95 liters), D2 (15.60 liters), D3 (21.50 liters), D4 (19.65 liters) and D5 (17.05 liters) (**Figure 6**). The cumulative

production total is 81.75 liters. It appears from these results that the substrate of digester D3 (50% Pig manure and 50% Cow dung) has the highest cumulative value of biogas products (21.5 liters) following by D4 (25% Pig manure and 75% Cow dung), 19.65 liters showing thus the co-digestion substrates remain the most favorable in anaerobic digestion for optimal biogas production [26] [27].

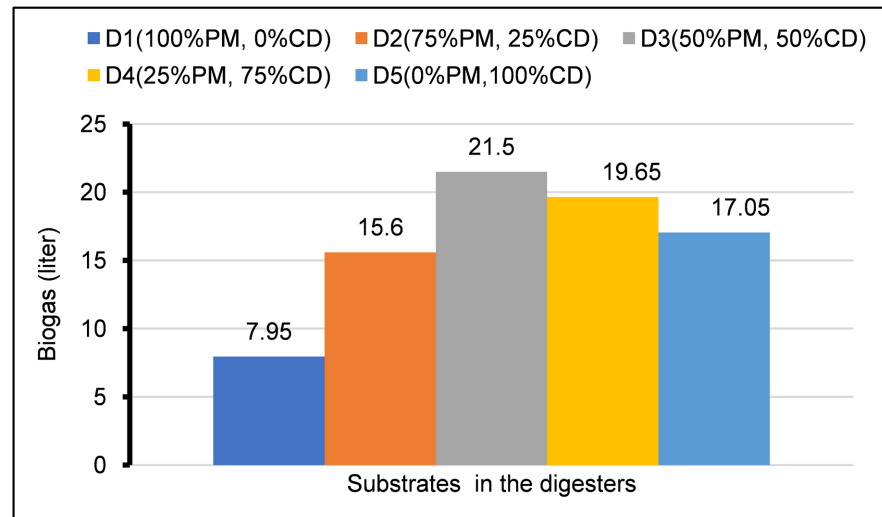
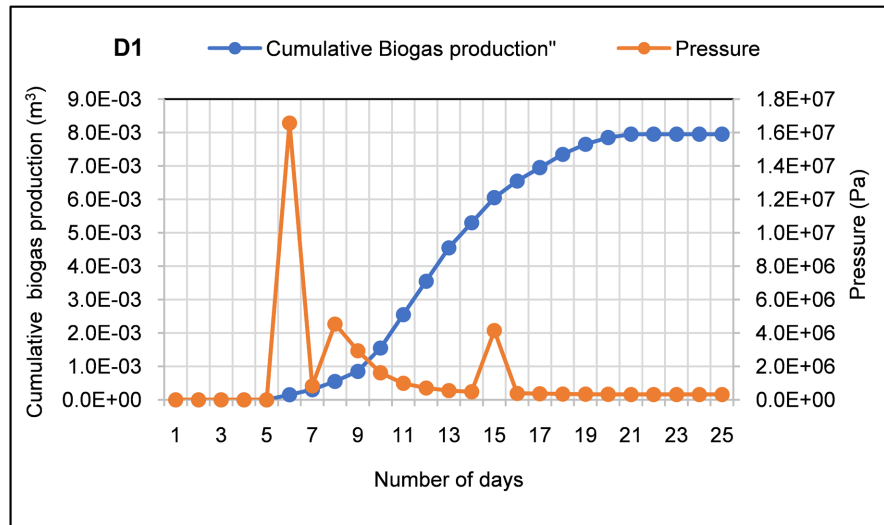


Figure 6. Cumulative biogas production of substrates in the digesters.

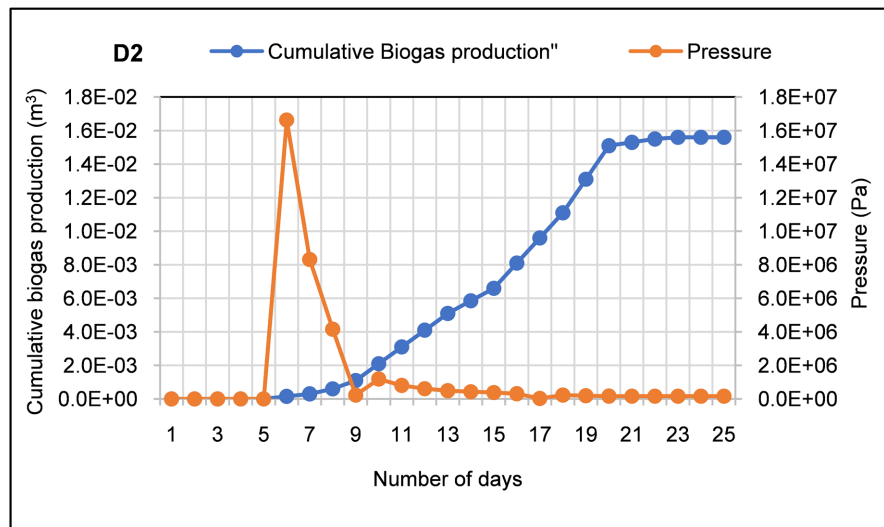
4.4. Cumulative Biogas Production

After following the evolution of biomethanization parameters of substrates (temperature, pH), we presented in this subsection the cumulative biogas production and the evolution of the pressure generated by their production. This is illustrated in **Figure 7** for biogas from the five digesters. It is observed that the pressure curves from the five digesters are the same trends. During the digestion process, the pressure of cumulative biogas varied in the five (5) digesters with different average values. 3.15×10^5 Pascal for the substrate of digester D1 (**Figure 7(a)**); 1.61×10^5 Pascal for digester D2 (**Figure 7(b)**); 1.16×10^5 pascal for digester D3 (**Figure 7(c)**); 1.28×10^5 pascal for digester D4 (**Figure 7(d)**) and 1.48×10^5 pascal for digester D5 (**Figure 7(e)**).

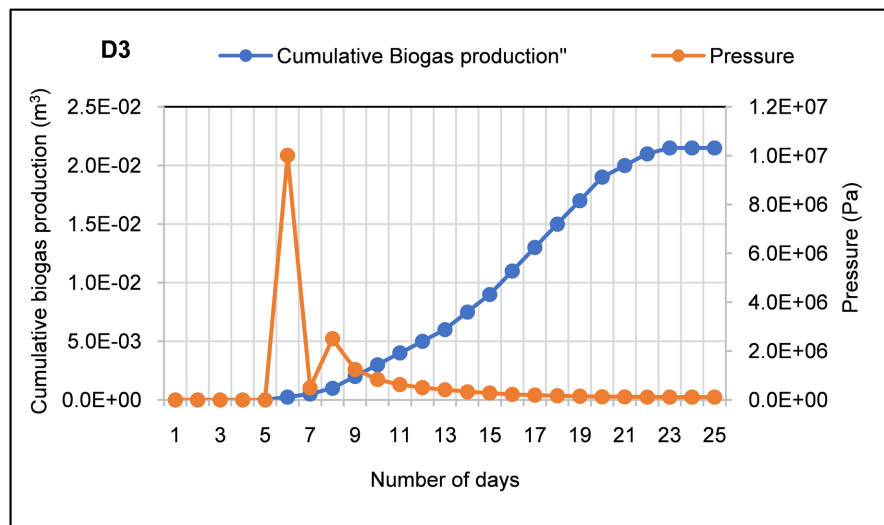
We observed three phases for the pressure curves (**Figures 7(a)-(e)**). *Phase 1:* A rapid increase of pressure followed by rapid decrease (5th day to 7th day) for digester D1 and D3 (**Figures 7(a)-(c)**), (5th day to 9th day) for digester D2 (**Figure 7(b)**), (3th day to 8th day) for digester D4 (**Figure 7(d)**) and (3th day to 6th day) for digester D5 (**Figure 7(e)**); *Phase 2:* a small increase of pressure (7th day to 8th day) for digester D1 and D3 (**Figures 7(a)-(c)**), (9th day to 10th day) for digester D2 (**Figure 7(b)**), (8th day to 9th day) for digester D4 (**Figure 7(d)**). This phase do not exist for digester D5; *Phase 3:* A decrease of pressure (10th day to 25th day) for digester D2, (8th day to 25th day) for digester D3, (9th day to 25th day) for digester D4, (6th day to 25th day) for digester D5, and (8th day to 14th day) for digester D1.



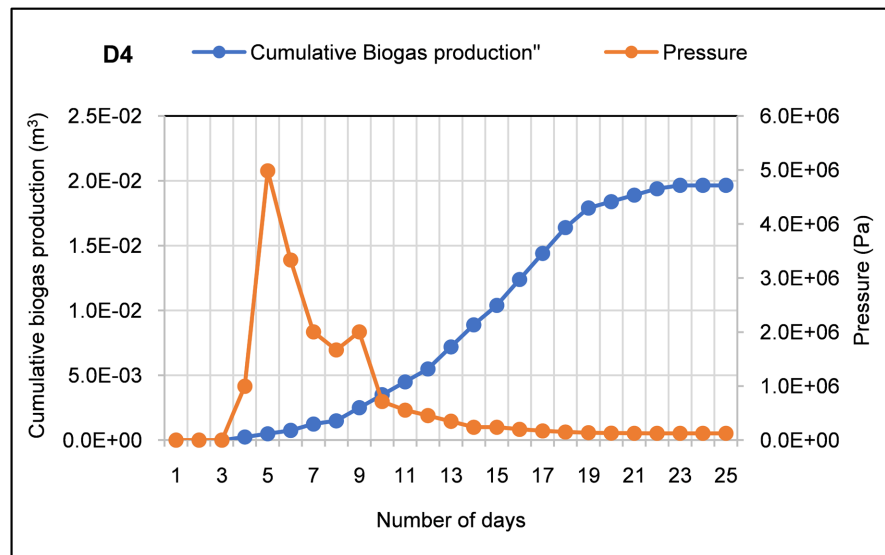
(a)



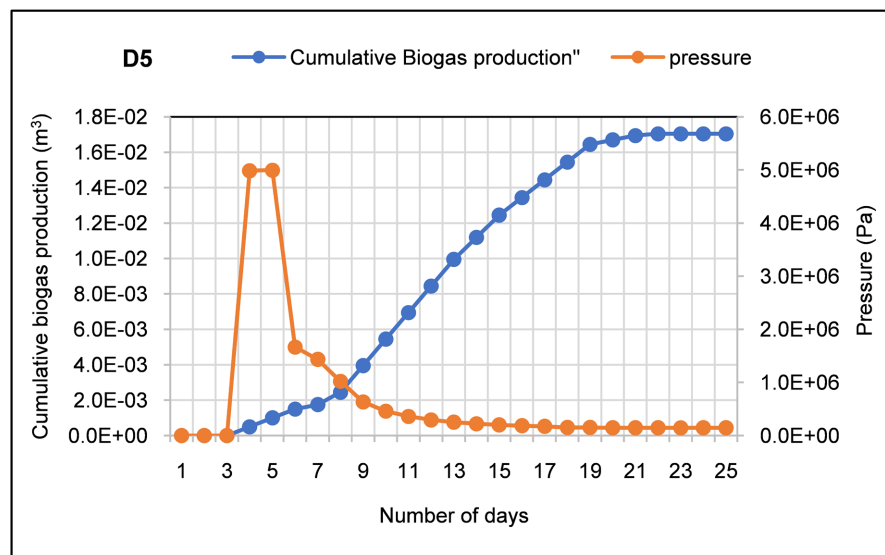
(b)



(c)



(d)



(e)

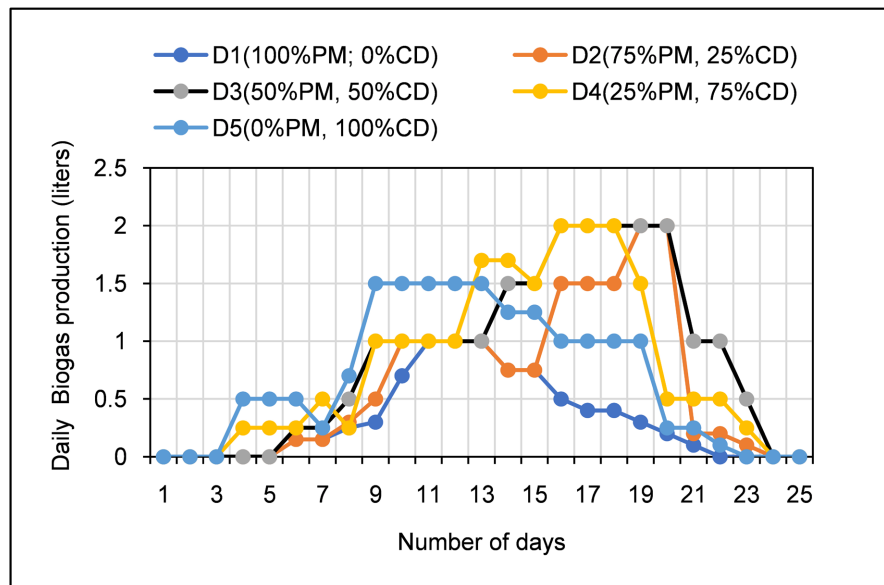
Figure 7. Cumulative Biogas production and pressure evolution in the digesters. (a) digester D1, (b) digester D2, (c) digester D3, (d) digester D4, (e) digester D5.

4.5. Biomethanization Parameters (Biogas Production, Temperature, pH) and Pressure Evolution

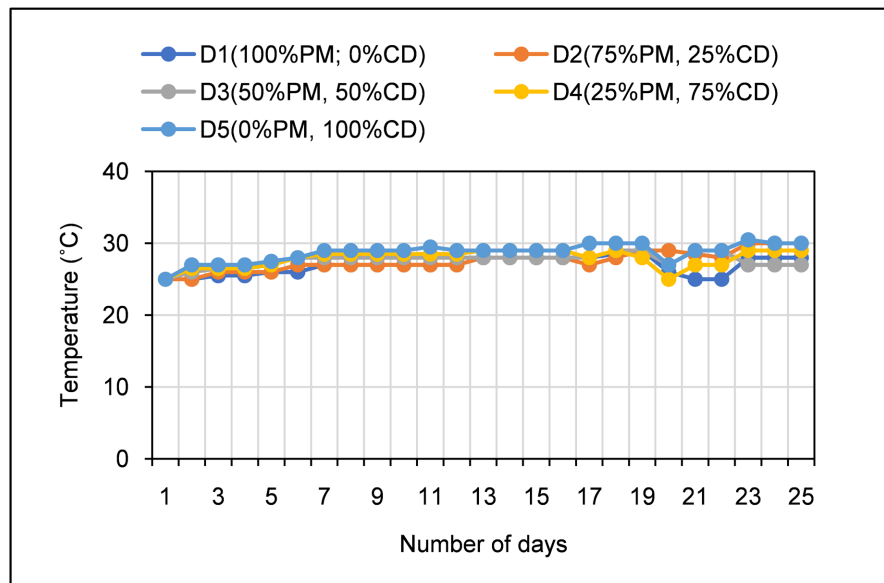
In order to obtain an overview of their daily evolution, we represented in **Figure 7**, the evolution the biomethanization parameters (biogas production, temperature, pH) and pressure of the cumulative biogas production for the substrates of the different digesters on the same graph. The results confirm the same interpretations of the **Figures 1-7**.

For daily biogas production (**Figure 8(a)**), it can be seen that during the 25 days of digestion, the largest quantity of biogas was recorded on the 15th day in the digesters (D3 and D4) with a value of 2 liters. The same value was recorded on the

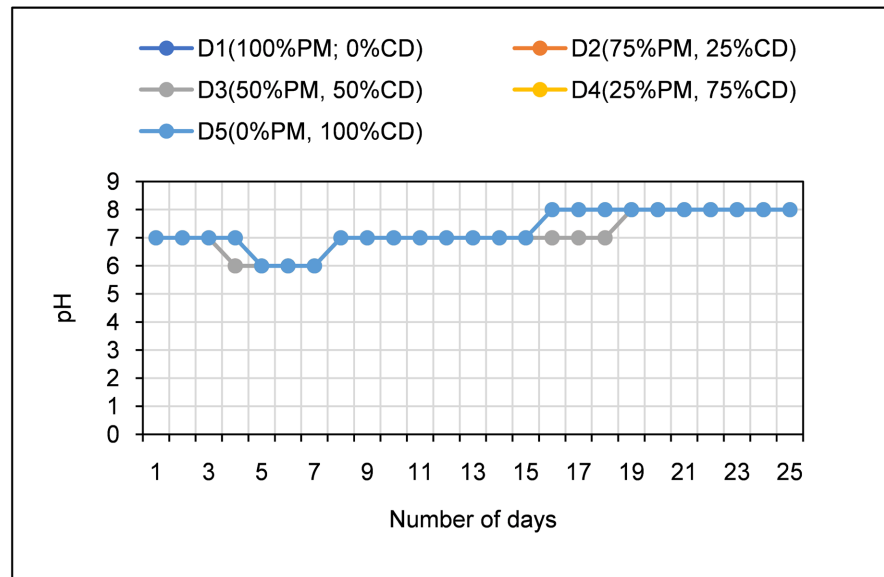
19th day in digester D2. The second largest value of biogas produced is 1.5 liters, recorded on the 8th day in digester D5 and the smallest value 1 liter was recorded on the 11th day in digester D1. For daily temperature evolution (**Figure 8(b)**), the temperature in the digesters D1, D3 and D4 varied from 25°C to 29°C. It varied from 25°C to 30°C in digesters D2 and D5. For daily pH evolution (**Figure 8(c)**), the pH variation curves of the substrates show that, during the digestion process, the pH varied from 5 to 8 in the five (5) digesters. For daily pressure evolution, it is observed the pressure curves in the five digesters are the same trends and during the digestion process, the pressure varied in the five (5) digesters with different average values.



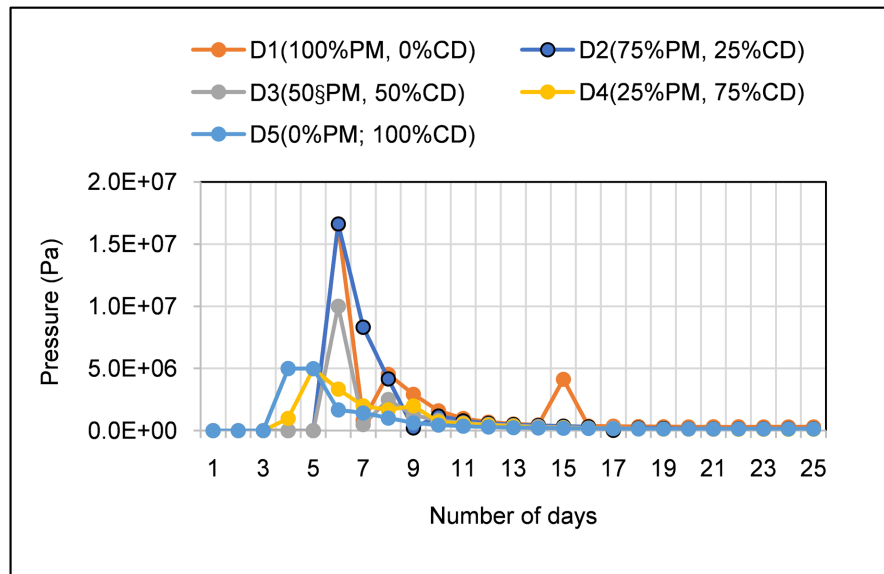
(a)



(b)



(c)



(d)

Figure 8. Biomethanization parameters (daily biogas production, temperature and pH) of the substrates in the digesters (a) (b) (c) and pressure (d).

4.6. Biogas Combustion Test

Biogas is a mixture combustible gas if the methane content is greater than or equal to 50%. The combustion of biogas is characterized by the release of a yellow or blue flame depending on the methane content. A persistent blue flame confirms the presence of methane in significant proportion (50%) or more [28]. The results obtained during this experimental study show that the biogas produced from the different types of substrates is combustible (**Figure 9**). The combustibility test revealed that the biogas produced by the substrates during the first two weeks was non-flammable. It was from the 15th day that the combustibility of the biogas

produced began, and it is from the 20th day that a significant quantity of methane with a stable flame was observed. It appears from this test, the quantities of biogas produced by the substrates (50%PM + 50%CD, 25%PM + 75%CD and 0%PM + 100%CD) respectively in the digesters (D3, D4 and D5) were very combustibles (**Figures 9(a)-(c)**). These test results confirm the importance of co-digestion of pig manure with cow dung in different proportions for combustible biogas production [29].



(a) substrate (50%PM + 50%CD): D3



(b) Substrate (25%PM + 75%CD): D2



(c) Substrate (100%CD): D5



(d) Substrate (100%PM): D1



(e) Substrate (75%PM + 25%CD): D4

Figure 9. Biogas combustion test.

5. Conclusion

This work allowed to develop an experimental biogas production model of Biogas using combination of pig manure and cow dung. The evolution of biomethanization parameters (pH, temperatures, daily and cumulative biogas production) and pressure of the substrates in the different digesters (D1, D2, D3, D4 and D5) were measured during biogas production process. The relation between the daily biogas production and the variation of temperature, pH were also examined as the

relation between cumulative biogas production and pressure evolution. The average daily biogas production of the five types of substrates obtained during the 25 digestion days, are: 0.32 liters for D1; 0.62 liters for D2; 0.86 liters for D3; 0.79 for D4 and 0.68 liters for D5. The temperature in the digesters D1, D3 and D4 varied from 25°C to 29°C. It varied from 25°C to 30°C in digesters D2 and D5. The average temperature value in the digesters are respectively 26.9°C for D1, 27.54°C for D2, 27.64°C for D3, 27.9°C for D4 and 28.73 for D5. The pH varied from 5 to 8 in the five (5) digesters, with averages of 7.12 for the substrates of digesters (D1, D2 and D3) and 7.28 for the substrates digesters (D4 and D5). During the digestion process, the pressure of cumulative biogas varied in the five (5) digesters with different average values. 3.15×10^5 Pascal for the substrate of digester D1; 1.61×10^5 Pascal for digester D2; 1.16×10^5 pascal for digester D3; 1.28×10^5 pascal for digester D4 and 1.48×10^5 pascal for digester D5. The cumulative production of biogas from pig manure and cow dung substrates in the proportions indicated in **Table 1** funded are: 7.95 liters for D1, 15.60 liters for D2, 21.50 liters for D3, 19.65 liters for D4 and 17.05 liters for D5. The combustibility test of biogas produced revealed the quantities of biogas produced by the substrates (50%PM + 50%CD, 25%PM + 75%CD and 0%PM + 100%CD) respectively in the digesters (D3, D4 and D5) were very combustibles. These test results confirm the importance of co-digestion of pig manure with cow dung in different proportions for combustible biogas production.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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