Open Journal of Applied Sciences, 2024, 14, 2679-2696
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Study of the Optimal Conditions for Anaerobic Digestion of Cow Dung in Households in Cote d'Ivoire

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How to cite this paper: Louh, S., Ori, T.R., Koua, K.B. and Gbaha, P. (2024) Study of the Optimal Conditions for Anaerobic Digestion of Cow Dung in Households in Cote d'Ivoire. *Open Journal of Applied Sciences*, **14**, 2679-2696.
https://doi.org/10.4236/ojapps.2024.149176

Received: August 8, 2024
Accepted: September 24, 2024
Published: September 27, 2024

Abstract

This paper investigates the optimal conditions for methanisation applied to cow dung. Four experimental 25 liters digesters were used in this work. The best biogas yield is obtained when the digester is installed in a metal box and exposed to sunlight. The temperature in this digester varied between 25˚C and 37˚C. The dry matter content of the collected cow dung was 15.5%. The digester was fed with 9 kg of cow dung mixed with 8.5 litres of water, one litre of cassava effluent and 200 ml of human urine. After a retention period of 22 days, the biogas obtained was 67% methane and 21% carbon dioxide. The use of human urine and cassava effluent improved the quality of the biogas.

Keywords

Methanisation, Cassava Effluent, Human Urine, Cow Dung, Biogas

1. Introduction

Energy is an indispensable element of modern society and can be one of the most important indicators of socio-economic development [1]. Despite technological advances, however, some three billion people, mainly in rural areas of developing countries, still meet their energy needs for cooking by traditional means by burning biomass resources in traditional stoves [2]. The inaccessibility to modern forms of cooking energy makes the living conditions of the people difficult, especially those of women who are usually responsible for collecting firewood. Fuel wood collection is also one of the main causes of deforestation and consequently of arable land degradation, which will endanger food security in the long term [3]. The current widespread and inefficient use of biomass energy also has implications for human health. Households could save time and energy, and have a supply of slurry that can be used as fertilizer in agricultural production [4]. To achieve sustainable development of the population in rural and urban areas, it is imperative that access to clean and affordable (renewable) energy is available. The implementation of household digesters is therefore a reliable opportunity to improve the living conditions of the population while preserving the environment. Indeed, the biodigester is a technological innovation that produces a combustible gas, called biogas [5]. The biogas produced enables rural households to carry out cooking tasks [6]. It contributes to the reduction of greenhouse gas (GHG) emissions from animal manure deposited on the ground [7]. Anaerobic digestion (AD) takes place in confined enclosures called digesters in which the fermentation reactions are optimized and controlled. The product of anaerobic digestion (biogas) is a mixture of 50% - 70% methane (CH_4), 50% - 30% carbon dioxide (CO_2) depending on the nature of the substrate [8]. The biogas produced from cow dung consists of 60% - 75% methane, 19% - 33% carbon dioxide, the other elements being in trace amounts. Biogas production with dung contains 67.9% methane and 27.9% carbon dioxide according to the work of Ukpai *et al.* (2012) [9]. However, there are several parameters that govern the proper conduct of anaerobic digestion. The most important of these are: pH, temperature, C/N ratio and substrate composition [10] [11]. The optimal values for these parameters are presented in **Table 1**.

Table 1. Optimal parameters for anaerobic digestion.

Parameter	Hydrolysis/acidogenesis phase	Methanogenesis
PH	5.2 - 6.3	6.7 - 7.5
Ratio C/N	10/1 - 45/1	20/1 - 30/1
Temperature range (˚C)	25˚C - 35˚C	32˚C - 42˚C (mesophilic) 50˚C - 58˚C (thermophilic)
Redox potential (mV)	−300 to +400 mV	Under −250 mV

Methanisation is a slow process due to the low growth rate of micro-organisms, it is pH sensitive and therefore needs a high buffer [12]. In most of the experiments conducted in the literature, the pH is self-regulated in the digester to reach optimal values. The pH regulation is mainly done by soda ash, sodium bicarbonate and calcium hydroxide [13] [14]. Alkaline pre-treatment is done with NaOH (sodium hydroxide), $Ca(OH)_2$ or ammonia to remove lignin. This process helps to make some of the hemicelluloses and cellulose accessible to enzymes. NaOH is found to be the best and sufficiently capable to increase biogas production by about 16.6% [15]. The addition of chemical compounds (sodium bicarbonate, lime, soda) increases the cost of implementing a household digester. Lack of expertise in the installation and maintenance of biogas technology hinders adoption in developing countries

[2]. Other enabling solutions need to be found to improve anaerobic digestion in households to control pH. The difficulties of households to respect these parameters are at the origin of the abandonment of the use of digesters in households due to the inhibition of anaerobic digestion (no biogas production) [16].

The production of biogas in households is confronted with some problems such as low or no biogas production, biogas leakage [16]. These difficulties encountered by households can be explained by the fact that in batch anaerobic treatment systems, the digester is fed at the beginning with the substrate and sealed during the whole transformation period. The fermentation reactions take place sequentially and when the biogas production drops or becomes zero, the reactor is emptied and new substrate is introduced [17]. However, the disadvantage of this type of reactor is the coexistence of all bacteria in the digester. This requires the maintenance of an environment favorable to anaerobic digestion. A neutral pH ensures the development and survival of methanogenic bacteria, but prevents the development of acidogenic bacteria. An acidic pH in which acidogenic bacteria grow is fatal for the methanogens that produce biogas [17].

Anaerobic digestion is very sensitive to temperature fluctuations which can lead to a decrease in system performance and biogas yield. The choice of a temperature between 32˚C and 42˚C allows to improve bacterial kinetics while favoring the metabolism of active microflora in the organic load [9]. The maintenance of temperature in the digesters also remains a serious problem. It is for these reasons and in the face of all these problems that several questions are raised:

- What are the locally available and low cost materials that can replace these chemicals to adjust the pH?
- Which system to realize at low cost for the control of the temperature in the digester in order to improve the quality and the quantity of the biogas?
- The addition of cassava effluent and human urine to the digester could replace chemicals to neutralize the pH of the substrate.
- Solar energy could be used for temperature control in household digesters.

The present work aims at improving the quality of biogas from cow dung using alkaline pretreatment with human urine and cassava effluent. On the other hand, to use a digester made of locally available materials, easy to move and affordable for households to produce biogas for cooking food in households.

2. Materials and Methods

2.1. Characterization

Fresh cow dung samples used in this study were collected at the INP-HB cattle farm. Human urine was collected in the latrine and cassava effluent was collected from women in Yamoussoukro.

2.1.1. Measurement of PH and Redox Potential

The pH was measured on 2 g of sample homogenized with 20 ml of distilled water using a pH meter (HAINA). The pH-meter is switched on and the probes are plunged directly into the different beakers containing the substrate. The value of these parameters is read directly on the digital display screen of the apparatus presented as follows [18].

2.1.2. Determination of Dry Matter

The dry matter was determined from 5 g of samples by differential weighing, after passing through the Heraeus T 5042 oven at 105˚C for 24 hours. The following formulas were used to calculate the dry matter (DM) and moisture (H) of cow dung [19].

$$\%\text{H} = \frac{M_0 - M_1}{M_0} \tag{1}$$

$$\%\text{DM} = 100 - \%\text{H} \tag{2}$$

With:

%H: percentage of moisture

M_0: initial mass of the sample before drying (fresh cow dung)

M_1: final mass of the sample after oven drying at 105˚C

%DM: dry matter

2.1.3. Organic Matter (OM)

The organic matter (OM) content is obtained by weighing the difference between the mass of the dry waste (M_1) and the mass of the waste calcined at 600˚C (M_2) to a constant weight for 2 hours [19].

$$\%\text{MO} = \frac{M_1 - M_2}{M_1} \times 100 \tag{3}$$

With:

M_2: the final mass of waste calcined at 600˚C

M_1: final mass of the sample after drying at 105˚C

2.1.4. Organic Carbon (%C)

The organic carbon content was deduced from the organic matter content after calcining the sample in a muffle furnace at 600˚C for two hours. The following formula is used to calculate the organic carbon [20].

$$\%\text{C} = \frac{\%\text{MO}}{1.8} \tag{4}$$

2.1.5. Nitrogen

Total Kjeldahl nitrogen takes into account two forms of nitrogen: total organic nitrogen and ammonia nitrogen. This determination consists of three steps: mineralization of organic nitrogen into ammoniacal nitrogen, distillation and titration [19].

- **Mineralization**

The 50 ml sample and 50 ml of distilled water (control) were introduced into matras mineralization tubes with the addition of 1 g of mineralization catalyst (selenium + potassium sulfate) and 10 ml of 95% - 97% sulfuric acid. The whole is heated to 350˚C for two hours in a fume hood. The reaction being exothermic, the tubes are cooled down to room temperature (25˚C).

- **Distillation**

After cooling, the acid is neutralized by adding 50 ml of soda 40% (NaOH). The mixture is placed in the distillation tank. The distiller's coolant line is then dipped into a beaker containing 20 ml of boric acid with mixed indicator (methyl red + methyl blue). The solution turns from blue to violet. The distillation is done during 10 minutes. At the end of the distillation, the solution turns green.

- **Titration**

The titration of the distillate is carried out with 0.1 N sulfuric acid. The return of the purple coloring marks the end of the titration, so the volume of 0.1 N sulfuric acid used is recorded.

- **Expression of the results**

The total Kjeldahl nitrogen (%N) is determined as:

$$\%\text{N}=\frac{\left(V_1-V_0\right)*N*14*1000}{V_2} \tag{5}$$

With:

V_0: volume of H_2SO_4 used to titrate the control (distilled water);

V_1: volume of H_2SO_4 used to titrate the sample;

V_2: volume of test sample;

N: normality of H_2SO_4 (0.1 N);

14: Atomic mass of Nitrogen.

2.2. Description of the Prototype Digester

The digester used in this research work was manufactured using polyethylene (plastic) drums. The experimental device is composed of two parts. The first part consists of a polyethylene canister of capacity 25 L of diameter 25 cm and height 50 cm. This tank contains the reaction medium, *i.e.* the substrate obtained after mixing the dung and water. The second part consists of the car air chamber which will trap the biogas produced during the methanization. The air chamber acts as a gasometer. The gasometer is designed for two reasons:

- To cover the biogas demand during hourly consumption peaks.
- And to contain the biogas production during the longest period of zero consumption [21].

Gas lines are used to connect the digester, air chamber and gas valve. The gas pipe is connected to the digester tank and the T-valve; and that the T-valve is connected to a rubber tube that connects a gas valve and the air chamber. The gas valve is used to burn the biogas. This prototype digester used in this work was manufactured in a workshop at the Mechanical and Energy Engineering Department of INP-HB.

A digital thermometer type TM-6 is connected to the digesters to observe the temperature variation in the digester. The synoptic diagram of these digesters is presented in **Figure 1**.

Figure 1. Schematic of the digester.

The objective of this work is to produce biogas at an affordable cost for households. Also to realize a digester easy to move. Thus our choice of materials for the realization of the digester was focused on the plastic can, the inner tube of car and the gas pipes. These materials are available locally.

2.3. Substrate of the Anaerobic Digestion

The organic waste used in this work is fresh cow dung collected from the cattle farm of INP-HB. Since pH plays an important role in considering the growth of microbial life during anaerobic digestion, a neutral pH is best suited for biogas production, since most methanogens grow at a pH range of 6.7 - 7.5. It is necessary to adjust the pH to maximize biogas production.

Kalloum *et al.* [10] studied the anaerobic digestion of household waste (kitchen waste) in two digesters, the first with pH adjustment around neutrality (pH = 7) with sodium bicarbonate and the second digester without pH adjustment; This study showed that the influence of pH on biogas production from household waste showed that adjusting the pH around 7 favors the growth of methanogenic bacteria that are responsible for methane formation. We also found that the amount of biogas produced in the adjusted pH case is twice as much as the amount produced in the unadjusted pH case [10]. Thus in this work, cassava effluent and human urine are used to neutralize the pH of the substrate. The urine of a healthy person. The characteristics of human urine and cassava effluent according to bibliographic sources are presented in **Table 2**.

Table 2. Characteristics of human urine and cassava effluent [22] [23].

	pH	Nitrogen (N)
Human urine	8.9	3600 mg/L
Cassava effluent	3.4	

Cassava effluent is acidic due to its composition (high starch content, presence of cyanogenic compounds). About 90% of the nitrogen is concentrated in urine

[23]. The main constituents of human urine (urea, sodium chloride, sodium sulphate) reveal that human urine has a basic character and can therefore replace chemicals such as lime, soda and sodium carbonate that are usually used to adjust the pH. According to these authors the pH of cassava effluent is 3.4 and human urine is 8.9 [22].

For the start-up of our digester, the maximum amount of effluent entering the digester is maintained at 80% of the total digester volume to avoid overfeeding the digester, which often leads to inhibition of anaerobic digestion [24]. The fermentation materials entering the digester are calculated at 8% to maximize the biogas volume during anaerobic digestion [25]. The mass of waste and the volume of water to be used are calculated based on dry matter (DM). Thus the mass of waste and the volume of water to be added to the waste to feed the digester are calculated as [25]:

$$m\left(\text{kg}\right)=\frac{80*\text{Vd}*8}{100*\text{MS}} \tag{5}$$

$$\text{Veau}\left(\text{L}\right)=m*\left(\frac{\text{MS}}{8}-1\right) \tag{6}$$

With:

Vd: The volume of the digester in liter

DM: Dry matter of the cow dung

Equations (5) and (6) are used to calculate the mass of cow dung and water to be used. The water to be added to the organic waste is heated to 40˚C, as heat is necessary for anaerobic digestion (AD) [26]. A mixture of waste and water is made until there are no lumps in the mixture and filtered [27]. The digester is stirred gently for three to five minutes each day after the introduction of the substrate [27]. The mixture of fresh cow dung and water at 40˚C is done as follows (**Figure 2**).

Figure 2. Mixture of fresh cow dung and water.

2.4. Starting up the Digester

The digesters are fed with 80% of the total volume of the reactors and the other 20% is reserved for the biogas that will be produced [27]. If the digester is overfed, acids will accumulate and methane production will be inhibited because microbacteria cannot survive in acidic conditions. Similarly, if the plant is underfed, gas production will also be low due to the alkaline solution, which is also not a favorable condition for anaerobic bacteria. Substrate sampling is performed before (inlet) and after (outlet) anaerobic fermentation in the different digesters. For the anaerobic digestion test, four experimental reactors were started one after the other.

Two digesters (**Figure 3**) were placed in the black painted sheet metal box exposed to the sunlight while the other two were placed in a room. The increase of temperature in the digester maximizes the production of biogas. The temperature variation is a very important element to take into account because it can irreversibly affect the quantity of methanization microorganisms. To control this temperature variation, the digesters are installed in black painted metal boxes. The box is painted black to absorb the heat [28]. An empty space of 5 to 10 cm is left between the digester and all the walls of the box [29]. This empty space acts as insulation material. In order to guarantee the fermentation process, the temperature inside the digester must be uniform; temperature fluctuations should be avoided as much as possible. However, small temperature fluctuations can be tolerated by the microorganisms of 2˚C to 3˚C/h per day [29]. The use of the metal box also prevents light from entering the digester during anaerobic digestion. Indeed, sunlight favors the production of algae inside the digester which reduces the production of biogas.

(a) In-cabinet digester with and without adjustment

(b) Digester installed in the laboratory with and without adjustment

Figure 3. The experimental digesters.

The biogas produced is recorded in an air chamber connected to the digester. Thus the calculation of the volume of biogas recorded is as follows (**Figure 4**):

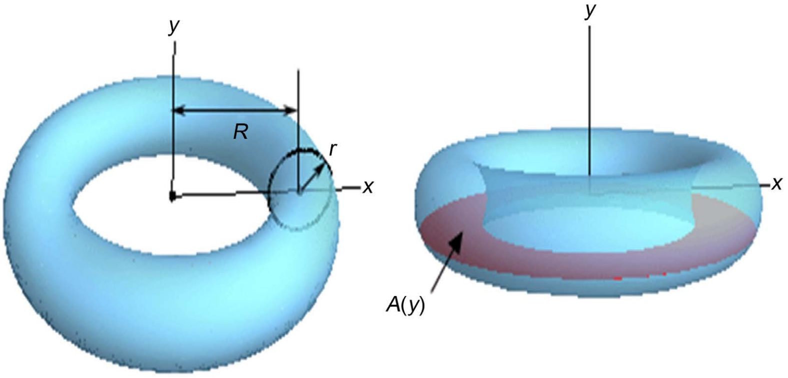

Figure 4. Calculation of the biogas volume from the air chamber.

The volume of biogas at the end of digestion can be calculated as [30]:

$$V = 2\pi^2 * R * r^2 \tag{7}$$

The four series of experiments presented above were conducted as follows:

- **Experiment 1:** The digester is installed in a room without pH adjustment.
- **Experiment 2:** The digester is placed in a room with pH adjustment with 200 ml of cassava effluent and 1 liter of human urine.
- **Experiment 3:** The digester is placed in the black box and exposed to sunlight without pH adjustment
- **Experiment 4:** The digester is located in the black box and exposed to sunlight with pH adjustment with 1liter of cassava effluent and 200mL of human urine.

All the digesters were operated in a discontinuous manner and were manually agitated on a daily basis before any sampling and measurements.

During the realization of each experiment, the filling of the digesters is done as follows:

- The prepared sludge is transferred into the digester using a small funnel.
- A digital thermometer connected to the digester allows the temperature in the digester to be known. The temperature is taken every two hours. This gives the average temperature in the digester per day.
- The pH values and the redox potential were taken twice, *i.e.* the first day before feeding in the digester and the last day of the experiment. The PH is taken twice because in batch anaerobic treatment systems, the digester is fed at the beginning with the substrate and sealed during the whole processing period.

The biogas production is calculated at the end of the experiment after 22 days. It is assumed that after 22 days the biogas produced reaches its maximum volume. The gas from the digester was stored in a tube for a flame detection test and biogas analysis.

To show that the gas that had filled the storage chamber (car tire) was flammable, a gas burner or valve is used.

2.5. Biogas Analysis

The quality of the gas obtained is the best key to appreciate each recorded production. The flammability test of the gas would allow to have a more precise idea on the nature of the gas, *i.e.* to recognize if the gas obtained is indeed biogas [3]. The analysis of the biogas allows knowing its composition (methane, carbon dioxide, etc.). The analyzer presented in **Figure 5** was used to analyze the biogas.

Figure 5. Biogas analyser.

3. Results and Discussion

3.1. Physico-Chemical Characterization of Fresh Cow Dung

In order to evaluate the capacity of the waste to produce quality biogas, these parameters (dry matter (DM), organic matter (OM) and C/N ratio) must be determined. Equations (2), (3) and (4) were used to determine these parameters. **Table 3** shows the values obtained from cow dung.

Table 3. Values of cow dung characterization.

Parameters	Dry matter (DM)	Organic matter (OM)	C/N
Value	15.5%	95.82%	28.78

The dry matter of cow dung used in this work is estimated at 15.5%. This value is in the range of 12% to 17%, the range in which the dry matter of cow dung oscillates [25]. Moletta [31] reports that the dry matter (DM) content of the substrate to be anaerobically digested generally determines the choice of anaerobic digestion processes and the type of anaerobic digester. The dry matter content of the study substrate (15.5%) confronts us with a "wet" anaerobic digestion which is adapted to the treatment of wastes having between 5% and 20% of dry matter (DM). The OM of 95.82% (DM), is slightly higher than the usual characterization of this waste. The range of OM of cow dung varies between 80% and 90% [1] [6]. High organic matter (OM) contents indicate preferred substrates for microorganisms in anaerobic digestion. A compound with high OM is rich in carbon because the relationship (4) shows that the percentage of carbon (%C) is related to the organic matter (OM). A substrate rich in carbon (C) produces a high proportion of methane, up to 90% [11].

The C/N ratio of cow dung is in the optimal zone for biogas production. Indeed a ratio (C/N) carbon-nitrogen of 20 to 30 represents an optimum for biogas production, while the excess of nitrogen or carbon sources can lead to inhibition.

From the values obtained from the cow dung (DM, OM and C/N), it appears that the cow dung is relatively biodegradable, easy to use for a biogas plant, already contains the right bacteria able to produce quality biogas.

3.2. Characterization of Cassava Effluent and Human Urine

The physico-chemical characterizations of the urine and cassava effluent used are given in **Table 4**:

Table 4. Effluent and urine parameters

	Cassava effluent	Human urine
Nitrogen (N)	0.41	2.4
PH	3.8	8.9

The physico-chemical characteristics of the cassava effluent show an acid effluent with a pH below 7 and a low quantity of nitrogen which is 0.41 g/L. These cassava effluents are biorecalcitrant because they are acidic (pH < 4) and present a nitrogen deficiency (0.6 - 0.8 g/L) according to [22]. The PH value of human urine used in this work is greater than 7 and rich in nitrogen (2.64 g/L). These values are not fixed; they can vary from one individual to another. Acidic human urine is sometimes found. However, the composition varies according to several factors such as the time of urination, type of food consumed and the physical conditions of the person concerned. The high content of nitrogen is explained by the high content of urea in human urine as mentioned in the thesis work of Youssef Abarghaz [23]. Because human urine is rich in nitrogen, it therefore has a basic character.

3.3. Analysis of Anaerobic Digestion Conditions

From the value of the dry matter (DM), we calculated the mass of fresh cow dung to be used as well as the quantity of water which it is necessary to add to the cow dung from the formulas (5) and (6). For a tank filled to 75% of its total volume, we used 9 kg of cow dung and 8.5 liters of water, heated to 40˚C to feed each digester (see **Table 5**).

Table 5. The mass of cow dung and water.

Parameter	Volume digesteur	Mass of fresh cow dung	Quantity of water
Value	25 litres	9 kg	8.5 litre

In each experiment, all the digesters were fed with 9 kg of cow dung + 8.5 liters of water at 40˚C. The feed substrate of the digesters in experiments 2 and 4 was adjusted with 200 mL of human urine and 1 liter of cassava effluent to have the pH of the substrate around neutrality (PH = 7). Before feeding the digester, the pH and the oxidation-reduction potential (ORP) were measured using a pH meter. After a retention period of 22 days, these same parameters were measured as well as the volume of biogas recorded. Table 6 gives the different values obtained in each experiment:

Table 6. The volume of biogas in the digesters.

Digesteur	Minimum temperature	Maximum temperature	pH adjustement	Initial pH	Final pH	Initial potentiel Ox/red	Final potentiel ox/red	Volume of biogas	Flammability test
Experiment 1	25˚C	28˚C	No adjustement	7.8	5.8	12.8 mV	7.14 mV	10.5 liters	No flame blue
Experiment 2	25˚C	28˚C	Addition of 200 mL of urine and one liter of effluent	7.00	6.4	12.3 mV	8.3 mV	11.845 liters	No flame blue
Experiment 3	26˚C	37˚C	No adjustement	7.8	7.4	14.8	−3.9 mV	40.845 liters	Flame blue
Experiment 4	26˚C	37˚C	Addition of 200 mL of urine and one liter of effluent	7.00	7.2	12.3 mV	−298.78 mV	430.750 liters	Flame blue

The digital pH meter described above was used to measure pHinitial, pHfinal, ORPinitial and ORPfinal. The digital thermometer connected to the digester makes it possible to measure the temperature in the digester. The biogas being stored in an air chamber. Once the inner tube is filled, the volume of biogas can be calculated using Equation (7).

- **Experiment 1**

This digester operated with a temperature varying between 25˚C and 28˚C without adjustment of the substrate. The initial pH of the substrate is 7.8 at the start of anaerobic digestion and 5.8 at the end of anaerobic digestion.

It is therefore obvious that the pH has dropped in the acid zone, therefore the methanogenic bacteria producing flammable biogas cannot survive in the event of acidification of the substrate. This therefore made it possible to obtain a non-flammable biogas at the end of the anaerobic digestion. This is visible through the redox potential which is also positive.

Higher or even positive values of the oxidation-reduction potential are the sign of a fermentation defect. This further confirms that biogas-producing methanogenic bacteria were not active in the digester during methanogenesis.

- **Experiment 2**

The difficulties encountered with the previous digester linked to the acidification of the pH led us to create a second digester always at a temperature varying between 25˚C and 28˚C but this time with the adjustment of the pH with 1 liter of effluent of cassava and 200 mL of urine. The initial pH after adjustment was 7.

On the other hand, at the end of anaerobic digestion, the pH dropped to 6.4. The favorable pH range for anaerobic microbes being 6.8 - 7.5.

Adjusting the pH with human urine and cassava slurry helped improve the pH around the optimal pH zone which is 6.8 - 7.5. The pH approaches around neutrality and the oxidation-reduction potential remained positive at the end of the anaerobic digestion. The biogas obtained is not flammable. As in the previous case, the methanogenic bacteria were killed in this digester.

The temperature varying between 25˚C and 28˚C did not allow the growth of methanogenic bacteria in this digester as long as the pH was adjusted. It is therefore clear that the temperature has a great influence on the growth of microorganisms [29]. The methanogenic phase takes place between 32˚C to 42˚C with 35˚C being the optimal value.

- **Experiment 3**

From these two experiments we found that at the temperature varying between 25˚C and 28˚C and unadjusted pH; at the temperature varying between 25˚C and 28˚C and adjusted pH it is impossible to obtain a flammable biogas. Therefore we found it judicious to observe the effect of the increase in temperature alone on the production of biogas. The digesters will no longer be inside the laboratory but the digesters will be exposed to the sun's rays. So we made digester 3 placed in a box painted black and exposed to sunlight without adjusting the pH. When the sun's rays strike the black metal box, it absorbs heat, which will help to increase the temperature in the digester. The empty space of 10 cm left between the digester and the walls of the box acts as an insulator which will prevent a large variation (sudden variation) of the temperature in the digester [28].

The average temperature in digester 3 measured using the thermometer is 31.5˚C, the initial pH is 7.8 and at the end of anaerobic digestion the pH is 7.4. The pH remained slightly above neutral; But the oxidation-reduction potential at the end of methanization was negative (−3.9 mV) which resulted in the production of a flammable gas of 15.8 liters. This volume was calculated using relation (7). The temperature increase of 31.5˚C favored the growth of methanogenic bacteria. The choice of a temperature of 31.5˚C makes it possible to improve bacterial kinetics while favoring the metabolism of active microflora in the organic load confirmed.

- **Experiment 4**

Admittedly, digester 3 gives flammable biogas, but the pH remained slightly above neutral; it is therefore important to see the effect of the pH adjustment. The results showed that the volume of biogas with digester 4 is twice the volume of biogas obtained with digester 3.

The significant quantity of biogas recorded in the case of digester 4 (in the black box and exposed to the sun's rays) is at two levels:

- An increase in temperature in the digester (26˚C to 37˚C).
- The pH adjusted to 7 with 200 ml of human urine and 1 liter of cassava effluent.

The addition of human urine, which has a basic character, and the acid cassava effluent in digester 4 raised the pH. The high production and flammability of biogas in digester 4 neutralized with human urine at the start of the experiment would be due to the almost neutral pH of the reaction medium and the increase in temperature (26˚C to 37˚C). This neutral pH would have made it possible to initiate methanogenesis in the reactors. These same results were obtained by Kalloum *et al.* (2007) [11]. According to these authors, methane production is high in the temperature range of 35˚C to 40˚C. The digester in the box exposed to the sun's rays with pH adjustment produces a high quantity of biogas (430,750 liters).

The values of the oxidation-reduction potentials remained negative at the end of the methanization leading to a flammable biogas. A low oxidation-reduction potential (ORP) is necessary to maintain the activity of methanogenic bacteria. Normally, the redox potential of non-methanogenic bacteria is in the range −100 to 100 mV, while that of methanogenic bacteria is in the range of −400 to −150 mV. The results obtained in this work are in agreement with Kalloum *et al.* (2007) [10] where a neutral pH and a mesophilic temperature favor the production of biogas.

3.4. Biogas Analysis

The anaerobic digestion parameters are significantly optimized when the digester is installed in the metal box and the substrate adjusted with human urine and effluent. Thus the biogas produced in this case is therefore analyzed in order to know the proportion of each constituent.

3.4.1. Flammability Test

Attempts to burn the gas produced were satisfactory at the end of the methanization, which means, and according to the literature, that the composition of our produced biogas is such that it is possible to recover it [3]. **Figure 6** gives the blue flame obtained in experiment 4 in a lighted (a) and dark (b) room.

(a) (b)

Figure 6. Biogas flammability test.

3.4.2. The Composition of Biogas

The methane contained in the biogas produced in experiment 4 is 67.1% and 21.1% carbon dioxide. The production of biogas with dung contains 67.9%

methane and 27.9% carbon dioxide according to the work of Ukpai *et al.* (2012) [9]. This present work improves the quality of biogas given the decrease in the proportion of carbon dioxide (21.1%) (**Table 7**).

Table 7. The composition of biogas.

Méthane	CO_2	O_2	H_2S	CO	O_2
67%	21.1%	17.9%	2 ppm	16 ppm	17.9%

3.5. Digestate Analysis

The fresh cow dung we used in this work has a C/N ratio of 28.78. When the sample was made by adjusting the pH with urine and cassava slurry, it had a lower C/N ratio. This drop in C/N is explained by the fact that urine is rich in nitrogen, so the addition of urine increases the amount of nitrogen in the substrate, so a reduction in the C/N ratio will be observed in particular. Human urine is generally used to reduce the C/N of organic materials with a high C/N ratio [23]. The sample adjusted with cassava effluent and human urine after analysis gives the results below. These different parameters are obtained before anaerobic digestion and after anaerobic digestion (**Table 8**).

Table 8. Characterization before and after anaerobic digestion.

	Before	After
PH	7.05	7.3
C	47.40	33.86
N	1.82	1.596
C/N	26.04	16.35
OM	83.40	62.77

During anaerobic digestion, the rate of organic matter in cow dung dropped from 83.40% to 59% at the end of methanation. There was a reduction in organic matter by more than half. During anaerobic digestion the rate of organic matter in many wastes or biodegradable by-products is halved. The pH at the end of anaerobic digestion is 7.2; this shows the stability of the digester and the process of anaerobic digestion. This reduction in organic matter shows a large consumption of carbon during anaerobic digestion [11]. The reduction of nitrogen during anaerobic digestion is low, it goes without saying that the digestate obtained after anaerobic digestion is rich in nitrogen as we can see in **Table 6**. The high proportion of nitrogen is due to the presence of urine in the final digestate. Urine contains the three most important plant nutrients that farmers buy and use as artificial fertilizers. Namely, nitrogen (80% of the organic nitrogen contained in our excrement is in the urine) [23], phosphorus and potassium are all the essential elements that plants need for their growth during their cycle. of development, which consists in passing from the state of seed to the production of another generation of seeds. Urine is therefore an excellent source of nitrogen for plants [23]; this digestate is therefore an excellent fertilizer, and can therefore be used by growers as fertilizer.

4. Conclusions

This study shows that adjusting the pH with human urine and cassava effluent before the start of anaerobic digestion is essential for optimizing the biomethanation process. This study also showed that the two parameters, namely temperature and pH, are more or less sensitive indicators of the operating status of anaerobic digestion. This study made it possible to clearly demonstrate that methanogenic bacteria are active when the pH is adjusted to 7 before methanization and an average temperature in the digester of 31.5˚C.

The amount of gas needed for cooking per person in households is 227 liters. The use of 9 kg of cow dung allows us to have only 350.75 liters of biogas. This quantity will not be able to cover the needs of a person; the need to increase the quantity of biogas becomes necessary by considering co-digestion of cow dung with household peelings.

In order to complete our study, it would be desirable to use the digestate produced (in the case where the methanogenic bacteria have a more intense activity) to seed in the anaerobic digestion of household waste. This will allow a housewife to produce her biogas with her waste that she produces for cooking her food and to reduce the time of biogas production below 22 days.

Conflicts of Interest

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

References

[1] Bolaji, G.E. and Adebayo, A.O. (2018) Biogas Production Potentials of Cassava Peels Co-Digested with Yam Peels Using a Batch Reactor at Mesophilic Temperature. *Journal of Engineering Research and Application*, **8**, 9-13.

[2] Surendra, K.C., Takara, D., Hashimoto, A.G. and Khanal, S.K. (2014) Biogas as a Sustainable Energy Source for Developing Countries: Opportunities and Challenges. *Renewable and Sustainable Energy Reviews*, **31**, 846-859. https://doi.org/10.1016/j.rser.2013.12.015

[3] Tize, J.K., Djoulde, D.R. and Ngakou, A. (2015) Influence du prétraitement mécanique et biologique des feuilles mortes de neem (azadirachta indica) sur la production du biogaz. *International Journal of Innovation and Scientific Research*, **16**, 505-513.

[4] Gwavuya, S.G., Abele, S., Barfuss, I., Zeller, M. and Müller, J. (2012) Household Energy Economics in Rural Ethiopia: A Cost-Benefit Analysis of Biogas Energy. *Renewable Energy*, **48**, 202-209. https://doi.org/10.1016/j.renene.2012.04.042

[5] Smith, J.U. (2013) The Potential of Small-Scale Biogas Digesters to Improve Livelihoods and Long-Term Sustainability of Ecosystem Services in Sub-Saharan Africa.

[6] Jyothilakshmi, R., Prakash, S.V. and Kedia, V. (2013) Portable Biodigester. *International Journal of Innovative Research in Science Engineering and Technology*, **2**, 3797-3803.

[7] Diop, F.T., Dieng, K., Wane, A. Sow, A., Kalandi, M. and Sawadogo, G.J. (2015) Avantages des biodigesteurs sur le bois de chauffe dans les élevages laitiers à Kaolack (Sénégal). *Agronomie Africaine*, **2**, 105-113.

[8] Rufai, I.A. (2010) A Review of the Evolution and Development of Anaerobic Digestion Technology. *Journal of Engineering and Technology*, **5**, 100-111.

[9] Ukpai, P.A. and Nnabuchi, M.N. (2012) Comparative Study of Biogas Production from Cow Dung, Cow Pea and Cassava Peeling Using 45 Liters Biogas Digester. *Advances in Applied Science Research*, **3**, 1864-1869.

[10] Kalloum, S., Khelafi, M., Djaafri, M., Tahri, A. and Touzi, A. (2007) Etude de l'influence du pH sur la production du biogaz à partir des déchets ménagers. *Journal of Renewable Energies*, **10**, 539-543. https://doi.org/10.54966/jreen.v10i4.756

[11] Faouzia, A. (2008) Caractérisation de la matière organique dans les ordures ménagères. Recherche d'indicateurs de stabilité. Thèse de doctorat Ecole Doctorale de Chimie de Lyon (Chimie, Procédés, Environnement).

[12] Rajameena, S. and Velayutham, T. (2018) A Critical Review on Biochemical Process of Anaerobic Digestion. *International Journal of Science Technology and Engineering*, **4**, 1-4.

[13] Matheri, A.N., Belaid, M., Seodigeng, T. and Ngila, C.J. (2015) The Kinetic of Biogas Rate from Cow Dung and Grass Clippings. *7th International Conference on Latest Trends in Engineering and Technology*, Irene, South Africa, 26-27 November 2015.

[14] Agu, C.S. and Igwe, J.E. (2016) Design and Construction of an Indigenous Biogas Plant. *American Journal of Engineering Research*, **5**, 88-97.

[15] Krishania, M., Kumar, V., Vijay, V.K. and Malik, A. (2013) Analysis of Different Techniques Used for Improvement of Biomethanation Process: A Review. *Fuel*, **106**, 1-9. https://doi.org/10.1016/j.fuel.2012.12.007

[16] Wijesinghe, L.C.A.d.S. and Chandrasiri, J.A. (1986) Operating Experience with Biogas Plants in Sri Lanka. *Natural Resources Forum*, **10**, 221-229. https://doi.org/10.1111/j.1477-8947.1986.tb00086.x

[17] Arras, W. (2017) Étude expérimentale et modélisation de la digestion anaérobie des matières organiques résiduelles dans des conditions hyperthermophiles. These de doctorat, Université du Quebec.

[18] Traore, D., Nikiema, M., Somda, M.K., Sawadogo, J.B., Dayeri, D. and Traore, A.S. (2016) Contribution à la biométhanisation de la biomasse végétale: Cas des résidus de légumes au Burkina Faso. *International Journal of Biological and Chemical Sciences*, **10**, 35-47.

[19] Afilal, M.E., Elasri, O. and Merzak, Z. (2014) Caractérisations des déchets organiques et évaluation du potentiel Biogaz. *Journal of Materials and Environmental Sciences*, **5**, 1160-1169.

[20] Subramani, T. and Ponkumar, S. (2012) Anaerobic Digestion of Aerobic Pretreated Organic Waste. *International Journal of Modern Engineering Research*, **2**, 607-611.

[21] Aboubacar, Z. and Boli, C.M.F. (2016) Mbofung, Etude du potentiel biogaz des déjections animales: Bouses de bovins et fientes de volailles d'un centre zootechnique à Maroua—Cameroun. *Revue des Energies Renouvelables*, **19**, 447-464.

[22] Kpata-Konan, N.E., Konan, K.F., Kouame, M.K., Kouame, Y.F., Gnagne, T. and Tano, K. (2011) Optimisation de la biométhanisation des effluents de manioc issus de la filière de fabrication de l'attiéké (semoule de manioc). *International Journal of Biological and Chemical Sciences*, **5**, 2330-2342.

[23] Youssef, A. (2013) Promotion Des Techniques d'assainissement Écologique Rural à

Des Fins de Valorisation des Eaux Usées—Cas Du Projet Pilote Du Douar Dayet Ifrah. Thèse de doctorat, Université Mohammed V-Agdal.

[24] Afazeli, H., Jafari, A., Rafiee, S., Nosrati, M. and Almasi, F. (2014) Investigation Yield and Energy Balances for Biogas Production from Cow and Poultry Manure. *International Journal of Renewable Energy Research*, **4**, 312-320.

[25] Al Imam, F.I., Khan, M.Z.H., Sarkar, M.A.R. and Ali, S.M. (2013) Development of Biogas Processing from Cow Dung, Poultry Waste, and Water Hyacinth. *International Journal of Natural and Applied Science*, **2**, 13-17.

[26] Mushtaq, K., Zaidi, A.A. and Askari, S.J. (2016) Design and Performance Analysis of Floating Dome Type Portable Biogas Plant for Domestic Use in Pakistan. *Sustainable Energy Technologies and Assessments*, **14**, 21-25. https://doi.org/10.1016/j.seta.2016.01.001

[27] Atilade, A.O., Onanugo, O.K. and Coker, J.O. (2014) Comparative Study of Biogas Generation from Chicken Waste, Cow Dung and Pig Waste Using Constructed Plastic Bio Digesters. *International Journal of Research Studies in Biosciences*, **2**, 47-51.

[28] Fitia Tsimbina, W.J. (2016) Le biogaz domestique pour une énergie alternative et la gestion des déchets à Madagascar. Master d'Ingénierie en Energies Renouvelables, Université d'Antarrivo.

[29] Paterson, M. and Kuhn, W. (2010) Guide sur le biogaz—De la production à l'utilisation.

[30] Ishaya, G., Jijingi, H.E. and Ngabea, S.A. (2016) Studies on Balloon Storage of Biogas for Anywhere Use. *International Journal of Engineering Research*, **5**, 709-711.

[31] Moletta, R. (2008) Méthanisation de la biomasse. *Technique de l Ingénieur*, *Bioprocédés et Bioproductions*. https://doi.org/10.51257/a-v1-bio5100