

HOUSEHOLD WASTE TO PRODUCE BIOGAS AND DIGESTATE BY A PORTABLE ANAEROBIC BIODIGESTER

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ABSTRACT

Household waste management addresses the problem of sanitation and hygiene in developing countries, humanitarian camps and heavily populated areas such as prisons. Poorly managed waste often causes serious health problems and premature death. Yet they represent a great source of energy and can be used in agriculture as fertilizer. In this paper we propose the biological treatment of household waste by a mobile biodigester model. The used device includes a methanol unit with a volume of 220 liters, a biogas storage unit and a digestate recovery unit. The cow dung combined with the crushed organic waste was mixed with the water in a 1/1 ratio, the whole was introduced into the methanization enclosure. The masses of biogas and digestate were determined for 40 days. The cumulative volume of biogas obtained gave the equivalent of 1994.35 liters. The produced digestate was introduced to the soil in a test field where the rice seeds were sown. The seed yield on an area of 81 m² gave 675.906 seeds. This yield was compared to a similar field where chemical fertilizers were used and the result obtained gave 689700 seeds. In addition, the analysis of the metals in the digestate gave a negative result.

KEYWORDS: Organic waste, biogas, digestate, biodigester, methanation

1. INTRODUCTION

Household waste management in developing regions, refugee camps and heavily populated areas such as prisons and mining areas is very difficult. The impact and damage of household waste on human hygiene and sanitation of living areas increases in overcrowded areas, as in congested humanitarian camps where refugees live together in temporary unstable conditions. These camps are established after emergencies, natural or man-made disasters, wars, earthquakes, floods and typhoons [1-7]. Biological treatment methods are the possible solutions for sustainable waste management. Anaerobic digestion is an alternative. It is a very complex biochemical process where the organic matter is degraded by microorganisms naturally present in a substrate.

Anaerobic digestion offers many benefits because it reduces the amount of waste by converting some of the organic matter into biogas. This biogas brings adapted solutions to the production of renewable energies as well as the reduction of greenhouse gases. The anaerobic digestion process also produces mature natural organic fertilizers useful for depleted soils [3, 5-6, 8-12]. The energy recovery of kitchen waste can also significantly offset the ever-increasing demand for fossil fuels. This paper presents a simple and easy-to-use solution for micro-production of biogas and digestate. A mobile biodigester model is proposed, its production of biogas and digestate is evaluated. Organic kitchen waste and cow dung are used to make it work.

The paper has four parts: the literature review, the steps of the methanation, the material and method then the results and the interpretation.

2. LITERATURE REVIEW

The first biodigesters were created in England in the city of Exeter in 1895 and in the leprosarium of Mantunga near Bombay in 1897. But it was in 1953 that the first biodigester was built in Los Angeles, it was working in thermophilic diet ; its production of biogas was limited and it was at this point that many experiments were conducted on biogas [13-18]. However the discovery of methane goes back to 1778 by Allessandes Volta and in 1808 English Sir Humpthrey Davy experiments the fermentation of manure by producing biogas and identifying it with methane. The term methane appears in 1892 and Louis Pasteur shows that the origin of this gas stems from a bacterial fermentation. Mobile biodigesters became popular in 1964 under the Khadi Plan and Industries Commission of India [19-22].

In Africa, technology remains less known and used very little across the continent. Nevertheless, Burundi and Tanzania have the largest facilities estimated at between 20 and 500 units. Technology is popularized through programs such as the African Biogas Partner-Ship Program (ABPP) which has supported the construction of 70.500 biodigesters in countries such as Burkina Faso, Ethiopia, Senegal and Tanzania during the period 2009-2013. In Cameroon the technology is embryonic, but initiatives of the Netherlands Cooperation Agency (SNV) have allowed to build 164 biodigesters in the Adamawa region by the project Domestic Biogas supported by the Ministry of Water and Energy during the period 2013 to 2015 [19-25].

On June 29, 2011, the Cameroon hygiene and sanitation company (Hysacam) inaugurated its first biogas capture station at Nkolfoulou near Yaounde. It was created to limit the nuisance associated with the presence on this site of a waste storage center with the added value of biogas. On November 20, 2014 the same company opened in Douala, the economic capital of the country, its second biogas capture and treatment plant. The company also plans, in the medium term, to convert the gas into electrical energy.

3. THE STAGES OF METHANIZATION

3.1. The production of biogas

The main stages of biogas production are [21,26-31]:

- Hydrolysis of biomass, a process in which hydrolytic bacteria degrade fresh organic matter (polymers) into soluble fragments (monomers). The rate of degradation depends on the substrates. Thus, it is important to mix the medium well to homogenize the solution and optimize the hydrolysis.
- The acidogenesis of simple molecules, the process in which acidogenic bacteria degrade simple molecules of organic matter (monomers) into acids and alcohols.
- Acetogenesis is a process in which the acetogenic bacteria transform AGV into acetic acid ($\text{CH}_3\text{-COOH}$) and H_2 and CO_2 . These molecules will then serve as a substrate for methanogenic bacteria. Acetogenic bacteria produce dihydrogen but their activity is inhibited by an excess of dihydrogen in the medium. Thus, the symbiosis of these bacteria with dihydrogen-consuming bacteria (especially methanogens) is essential to ensure good bacterial activity in the digester. Acetogens and methanogens live fixed to each other, rapid agitation may destroy this link hence the recommendation of slow mixing.

• Methanogenesis is the last stage of anaerobic degradation of organic matter. The microorganisms that perform this step are methanogenic bacteria. There are two groups of methanogenic bacteria, hydrogenophiles (which use H_2 and CO_2) and acetoclasts (which use acetic acid). In both cases, they will reduce their substrate to methane (CH_4). The average composition of the biogas thus produced is a mixture of CH_4 (60%) and CO_2 (40%) with traces of H_2S , NH_3 and H_2 . These methanogenic bacteria have the peculiarity of developing under strict anaerobic conditions; they are totally intolerant to dioxygen. They also need nickel (Ni) to grow. Thus, it is important to guarantee a total absence of oxygen in the digester as well as a satisfactory Ni input for their growth (in general the quantity of nickel contained in the organic material entering the digester is sufficient). Methane is formed mainly by oxidation of acetate (70%) and in a minor way by reduction of hydrogen (30%) [21, 26-31].

The general scheme of biogas production is as follows:

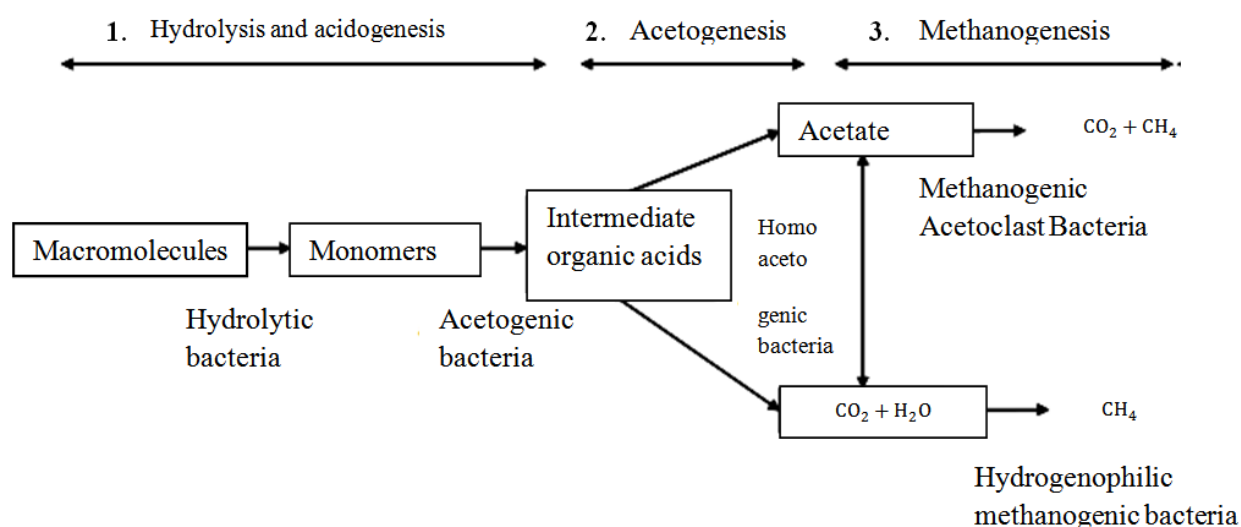


Figure 1: The stages of anaerobic digestion

3.2. The production of digestate

The methanation leads to the production of an organic residue called digestate; this residue contains little carbon because it is extracted from the mixture that produces the biogas. On the other hand, other elements such as nitrogen, phosphorus, potassium, magnesium and sodium make digestate an excellent fertilizer. The digestate is considered waste and must be spread according to a spreading plan, it can be spread as is or undergo post-treatment before being valorized [28-31]. However, digests (solid and liquid) can be used in nurseries, in agricultural production around

refugee camps, in reforestation and revegetation of abandoned mine sites. The positive aspect of digestate spreading has been demonstrated in many studies [28-31]. It is noted that the production of biomass increases with the repeated application of the digestate and that for the same number of applications, the larger doses produce better results.

The development of biogas and digestate can enable the production of a more appropriate renewable energy, the development of agriculture, forest heritage and livestock [28-31].

4. MATERIAL AND METHOD

In this part, it will be a question of presenting: the material which was used for the design of the experimental unit of anaerobic digestion, the organic waste and the procedures of characterization of by-products of anaerobic digestion.

4.1. MATERIAL

4.1.1. Material composition

The material used to design the experimental unit consists of:

- Equipment from the anaerobic digestion unit (photo 1, photo 2 and photo 3) purchased from a hardware store in the city of Yaoundé (one 220-liter PVC barrel, two bladders, four 16-mm diameter fittings, two jerry cans). Five liters, three female valves, PVC pipe 40 cm in diameter and 1 meter long, compression hose 16 cm in diameter and length 50 cm, PVC female valve 63 cm, PVC pipe 63 cm in diameter and one meter long, two PVC elbows 40 cm in diameter, one T 16cm diameter, one pressure gauge, six steels and six hooks, PVC glues and a reduction of 100 by 63.



(a)



(b)



(c)

Photo1: (a) Compression Courtyard 16 male; (b) Amboue with compression 16 female; (c) 16/16 Compression Valve

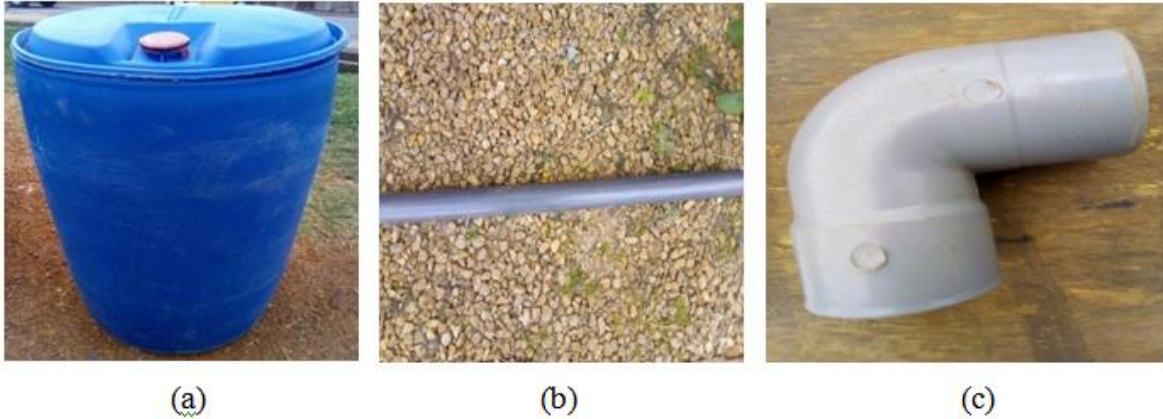


Photo 2 : (a) PVC Barrel 220Liter (b) PVC pipe (c) PVC elbow



Photo 3: (b) Gas pipe; (c) Ecrossite glue; (d) Pegasfor adhesive



(a)

(b)

Photo 4: (a) Super glue ; (b) Storage Bladder

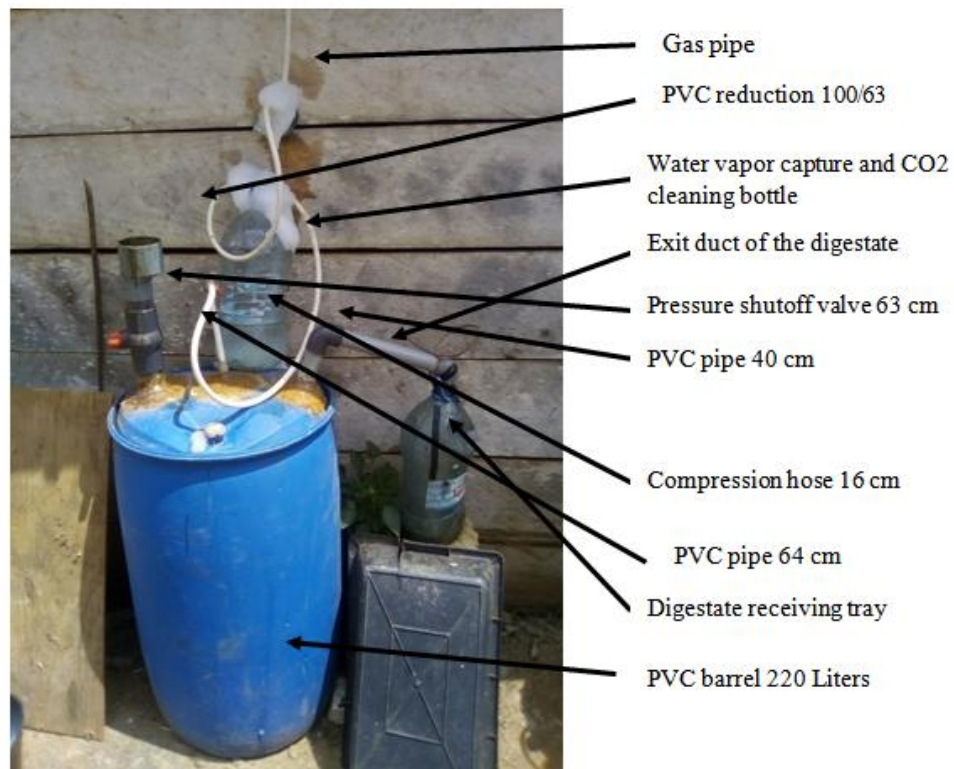
- Organic material used to operate the anaerobic digestion unit (organic kitchen waste, *Tithonia diversifolia* leaves and cow dung as inoculums)

4.1.2. Experimental methanation set-up

The experimental set-up (photo 5a-b) comprises a 220-liter PVC barrel on which were drilled three holes on the upper face of respective diameters: 64cm, 17cm, and 41cm. The 17 cm hole helps the gas exit; it will fix a 16 cm diameter aluminum water pipe containing a female stop valve of 16. In the hole of 64 cm we have introduced a pipe of 63 cm of diameter will serve as the entrance path of the substrate, this 63 cm pipe carries at its entrance a 100/63 size funnel and a stop valve which prevents the rise of the substrate under the action of the gas pressure formed. We fixed on the hole of 41cm a pipe of 40 cm which consists of elbows which direct the digestate in the tray of reception. All pipes are connected to 220-liter PVC with PVC binders such as super glue, pegafort to seal and prevent contact between inside and outside and make the environment anaerobic. A gourd containing water was installed to collect water vapor and allow the immersion of the carbon dioxide contained in the biogas.

The experimental methanization unit is presented in photo 5. Overall, these photos highlight the main parts of the continuous feed experimental unit. Thus, the operating principle can be described as follows. The substrate is introduced into the 220 liter PVC cask after having been diluted in water and then homogenized. The barrel is hermetically closed. During the production phase, the biogas released is stored in the bladder following the opening of the gas duct valve. It is captured by the pipe that connects the barrel to the latter. Moreover, the entry of a given amount of

the fresh substrate into the digester systematically repels the same amount of the digested substrate in the discharge.



(a)

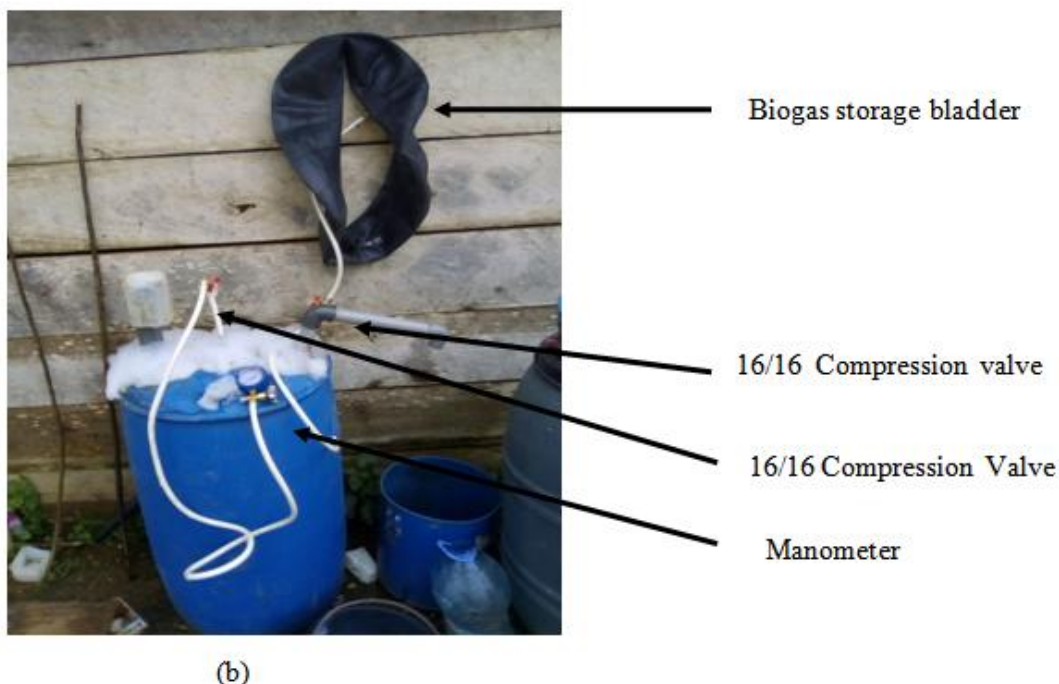


Photo 5: (a) Experimental methanation set-up (b) leak test

4.1.3. Organic matter

The kitchen waste, photo 6, photo 7, photo 8, and photo 9, was cut, crushed and mixed with cow dung and water then introduced into the biodigester, where they were completely consumed by the losing microorganisms. Their initial form to turn into a muddy paste consisting of a liquid phase and a solid phase called digestate.



Photo 6: kitchen waste



(a)



(b)

Photo 7: *Tithonia diversifolia* leaf (a); (b) Cow dung harvest



(a)



(b)

Photo 8: Pretreatment (a); Preparation of the substrate in a mixing basin (b)

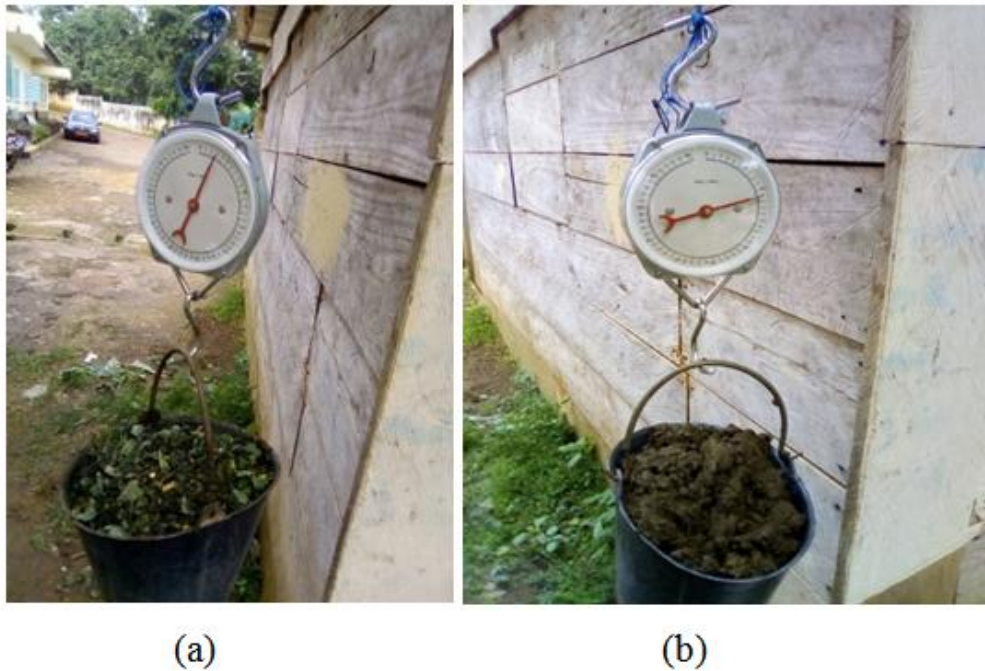


Photo 9: (a) Weigh vegetable organic matter; (b) Weigh cow dung

4.2. METHOD

This part explains the mode of supply of the digester and its mode of operation.

4.2.1. Method of calculating the volume of biogas

After the design of the mobile biodigester, 83 kg of organic material was weighed using a 0.1g precision sensitive balance. The organic material was introduced into a mixing basin, to which water was added in a 1/1 ratio. The assembly constituting a substrate of 166 kg. Once the unit loaded with substrate, the anaerobic digestion process can then begin and the product gas is stored in a bladder connected to the gas outlet pipe. The water collection gourd, the storage bladder is connected to the biodigester by the gas pipes and female and male sockets.

The volume of biogas produced is evaluated as follows: A mass of the vacuum bladder is determined using a scale, and then as this bladder stores the gas, the masses after each day are determined. From the mass of the storage bladder, knowing the density of the biogas, the volume of the gas obtained is calculated by the formula below:

$$V = \frac{m_r - m_v}{D}$$

V: volume of biogas; m_v : empty mass of the bladder; m_r : mass of the bladder after filling; D: density of the biogas.

Biogas combustion tests are produced to determine the characteristics of its combustion. Among others, the color of the flame, the carbon deposits on the pot.

4.2.2. Fertilization test method of digestate

The tests were conducted on the farm of the rice project IRAD Yaounde Cameroon. Comparative tests have been set up for rainfed rice (orizativa): rice added to chemical fertilizer; Control Rice (not added); Rice added to the digestate. Each treatment was repeated three times and placed in cassettes 9 m apart. The experiment plan was obtained after performing a random draw. The experimental design is presented in Figure 2:

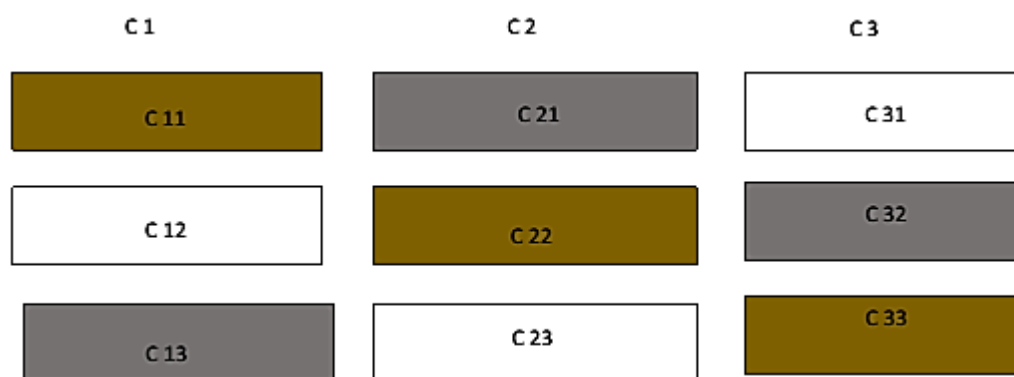


Figure 2: Experimental design

The main objective of the trials was to evaluate the fertilizer potential of the digestate in the field. The following parameters were tested: Plant yields; Appearance and color of the plants. After 70 days of experience, a visual analysis of the appearance of the plants was carried out as well as an evaluation of the nutrients contained in the digestate.

The nitrogen dosage was measured. The nitrogen concentrations were obtained by colorimetry with a wavelength of 655 nm.

The assay of the samples was obtained using the mass spectrometer. The pH determination of digestate samples began with filtering using wattman paper. The pH of the samples were obtained by direct reading on a pH meter. The pH of the reaction medium was gradually determined to know if the microbial activity is effective during the hydraulic retention time.

Metals were also assayed by filtering the samples using wattman paper and the presence of the metals was determined by mass spectrometry.

4.2.3. Functioning of the experimental methanation set-up

When the unit was first refueled with a three-quarter substrate, the biodigester created an anaerobic environment. After six days, the air outlet valve was closed; 4 days later, the digestate was poured, thus testifying to the proper operation of the biogas plant and the production of the biogas, after which the biogas produced was stored in the bladder, photo 10a. A constant intake of the pH allowed having a pH range (photo 10b).

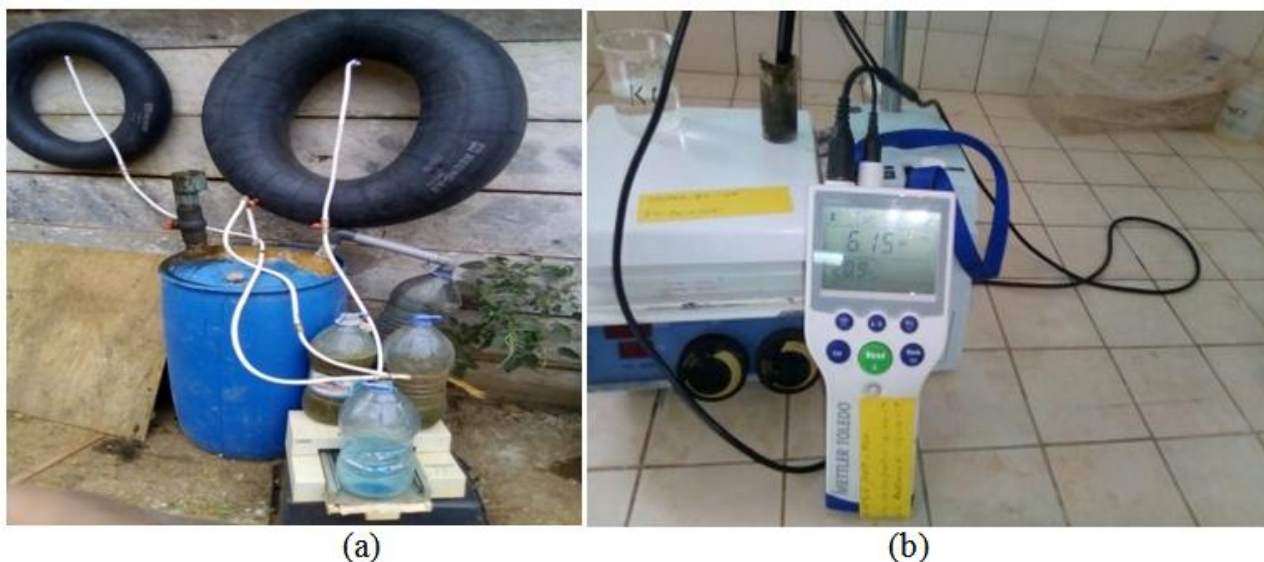


Photo 10: (a) Operation of the biodigester (b) Measurement of the pH of the reaction medium

5. RESULTS AND INTERPRETATION

5.1. Interpretation of biogas production curves

The bladder containing biogas was weighed; the difference in mass loaded and empty mass gave the mass of biogas produced after each day. Figure 3 shows the superimposed curves of biogas production in mass and volume per day. The mass and volume production curves vary in a similar way. We notice that the first ten days the production of biogas was important and fast because: the medium was inoculated with microorganisms contained in cow dung; the diversity of the mixture and the abundance of the organic matter gradually consumed by the bacteria. After the first 15 days,

production becomes irregular due to changes in ambient temperature. From the fortieth day, production becomes negligible.

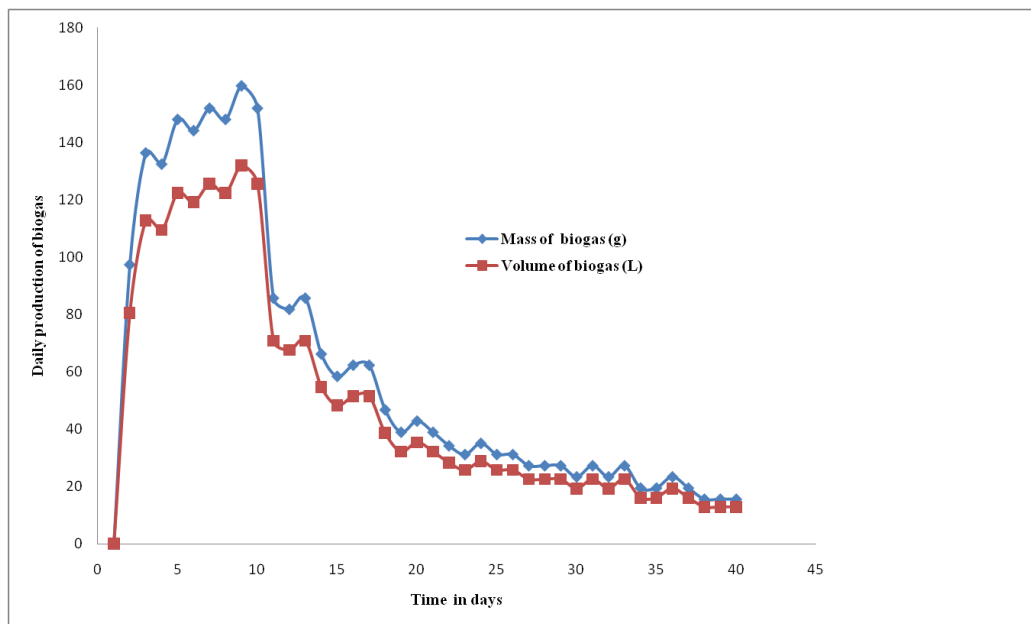


Figure 3: Kinetics of daily biogas production

5.2. Interpretation of biogas combustion tests

During combustion, we observed two main characteristics of this gas, the color of the flames and the deposit of carbon monoxide on the pot. Photo 11, shows that the flames produced by the biogas have a blue appearance. This color confirms the description relating to the combustion of methane. Moreover, it allows estimating that the combustion is complete. And therefore, there would be almost no carbon monoxide (CO). In addition, after a week of use of the pot for cooking with biogas, it is difficult to detect the black trace induced by CO on it.



Photo 11: Biogas combustion test

5.3. Interpretation of the fertilizing potential of digestate

5.3.1. Interpretation of digestate tests on control fields

The digestate is the residue of the methanation process after digestion of the organic matter by the microorganisms. It flows under the pressure of the gas and during a refueling of the biodigester in substrate. The observation of the digestate in the collection basin at rest, allowed seeing two large phases (photo 12): the liquid phase and the solid phase which was separated by decantation. The solid part was stripped of water to be dried, crushed and to obtain a biological fertilizer in the solid form. In addition, the liquid portion was stored in a closed bottle to prevent volatilization of nitrogen losses.

The mineralized sludge (photo 12) coming out of the experimental biodigester is recovered and dried in the shade to obtain fertilizer ready for spreading. This fertilizer provides the soil with nutrients and humus.

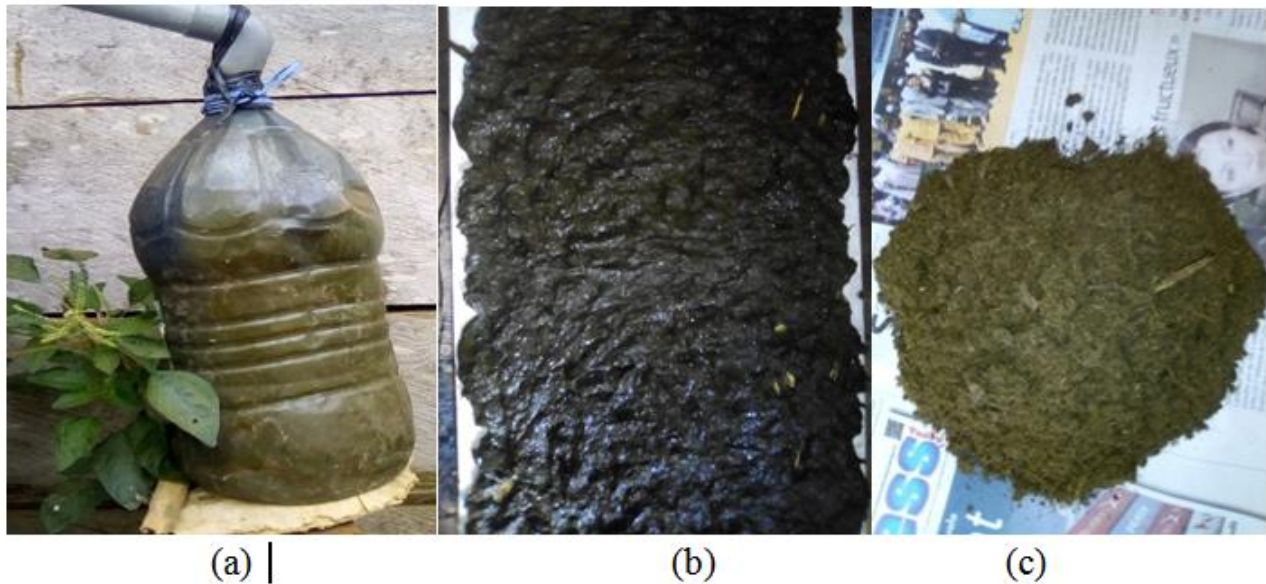


Photo 12: (a) Recovery of the Digestate; (b) Fresh solid digestate; (c) Dry solid digestate

The digestate thus dried was directly spread on the plot according to a test plan homogeneously followed by a mixture on the ground. The application of digestate on the test plot is shown in Photo 13.

The darker part contains the spread digestate and the lighter part does not contain the digestate.

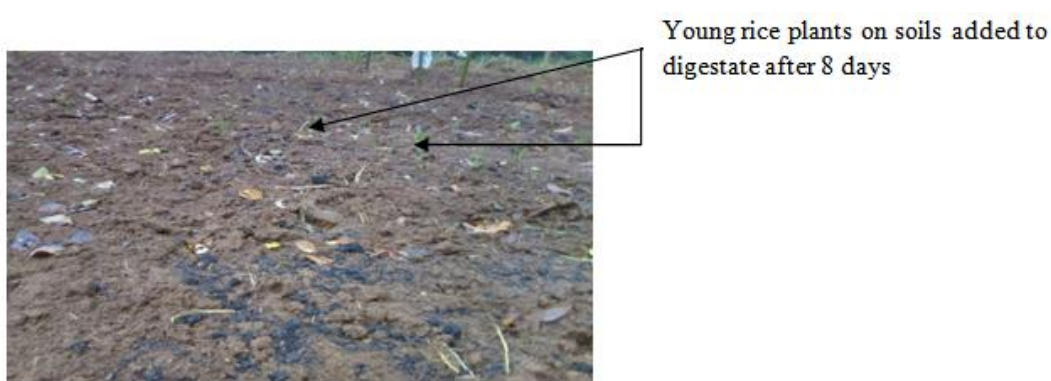


Photo 13: Spreading of digestate for nerica rice cultivation

5.3.2. Evaluation of the fertilizing potential of the digestate

The rice seeds germinated rapidly, seven days after sowing we observed 9 seedlings on the plot not added to the digestate; while on the added plot we observed 26 young plants (photo 14). The difference is very significant which allowed us to see that the digestate is responsible for the germination of the rice seeds. After 70 days of experience, the calculation of the yield and a visual observation of the plants illustrated by (photo 14) (size, color and length of the plants) enabled to highlight the effectiveness of the fertilization by the digestate.

The following characteristics were highlighted:



(a) Rice plants after germination

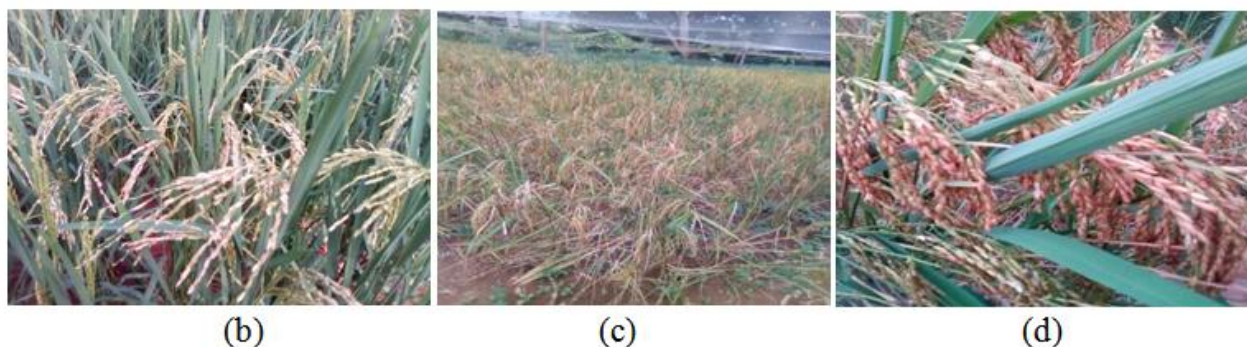


Photo 14: (a) Rice plants after germination (b) rice fertilized with chemical fertilizer; (c) control (unfertilized) rice and (d) fertilized rice by digestate

- **Appearance and color of plants**

After observation of the spaces, we find that the green color of the plants leaves added to the digestate and the chemical fertilizer is much more pronounced than that of the untreated plants leaves (photo 15). These differences in leaf color show a nitrogen contribution from digestate and

chemical fertilizer treatments. The green color of the leaves is an indicator of a soil rich in nitrogen [32-33]. There was also a better development of the root system and plant stems growing on the plots together with digestate and chemical fertilizer. The development of roots and stems is an indicator of a soil rich in potassium [32-33].

- **Plant yield**

Seed yield was evaluated as follows: The rice stalks were randomly sampled from the fertilized areas. By observation and by counting, we noticed that a rice stalk carried on average 11 panicles and a panicle carried on average 288 to 300 seeds of rice in parcels added to the digestate which allowed us to have a yield of 675906 seeds for a plot of 81 m² having 209 rice stalks. In a similar way, the crops of the chemical fertilizer added part gave us about 689700 rice seeds. We note from the calculation of the yields of different treatments, that there is no significant difference.

- **Evaluation of the nutrients contained in the digestate**

The evaluation of the nutrients contained in the digestate was carried out at the IRAD laboratory in Yaounde. Photo 15 shows filtration of the digestate to the filter paper and funnels. The filtrate is recovered in beakers.



Photo 15: Filtration device of the digestate

The liquid portion of the digestate thus obtained is labeled and then a mass spectrophotometer reading directly connected to a computer is performed (Photo 16).

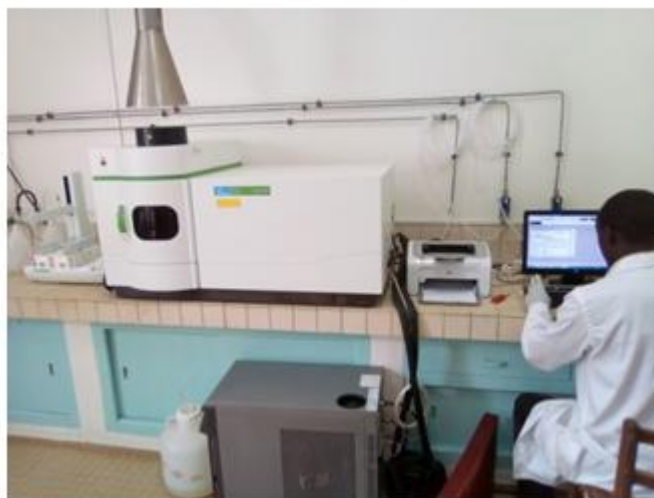


Photo 16 : Digestate analysis device

- **pH evaluation**

Table 1 shows the pH results over 35 days. The pH values vary very tiny and are between 6.60 and 8.44 while the recommended pH is between 6.5 and 8.5.

Table 1: pH Determination Results

Samples	E9 / 5 days	E10/10 days	E11/15 days	E12/ 20days	E13/25 days	E14/30 days	E15/35 days
pH	8.44	7.85	7.80	7.85	7.73	6.60	7.72

5.3.3. Nutrients evaluation

Figure 4 shows the kinetics of concentration of the following elements: Ca^{2+} , Mg^{2+} , K^+ and N. The graphs variation (Figure 14) allows to observe that the concentrations of calcium (Ca^{2+}), potassium (K^+), nitrogen (N) and magnesium (Mg^{2+}) are increasing as a function of time, moreover the presence of metals such as iron, zinc, copper, cadmium, lead, arsenic, manganese, selenium is zero after mass spectrometer analysis. . These results confirm that this fertilizer is not harmful to the environment, plants and soil.

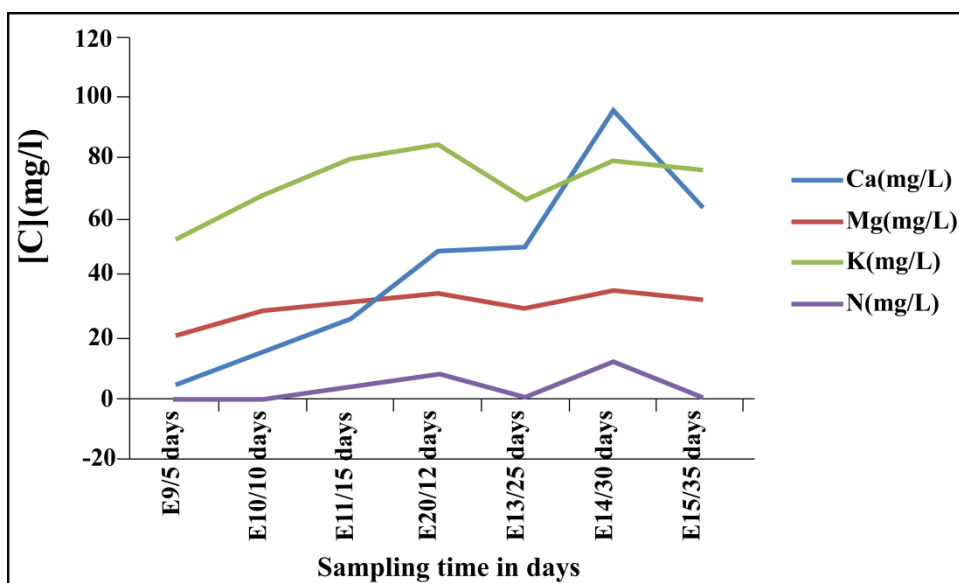


Figure 4: Curves of calcium, nitrogen, potassium, magnesium concentrations as a function of time

Overall, we find on the basis of table 2 that the biogas yield is relatively low compared to the digestate yield for our mobile digester. For the simple reason that the anaerobic digestion test was experimental and that we have repeated our experiment over 40 days, however the quantities obtained can burn for one to two hours depending on the quality of the burner used.

The yield of digestate is close to half of the organic matter introduced into the biodigester, respecting the principle of what enters is substantially equal to what comes out.

Table 2: Yield of biogas and digestate

Substrate quantity	Quantity of biogas produced	Quantity of digestate produced	Biogas yield	Yield in digestate product
182Kg	2.28337Kg	80Kg	1.254%	43.24%

6. CONCLUSION

The aim of this work was to propose a mobile biodigester model that can produce biogas and digestate using kitchen waste. We have described the characteristics of the different products obtained. The biodigester is composed of a 220-liter barrel as a biogas enclosure to which we have incorporated accessories. This methanation device to operate is supplied with a three-quarter substrate. The substrate is prepared by harvesting the organic waste that has to be ground, weighed and combined with the cow dung then all is mixed with water. Once the methanation device refueled substrate, the enclosure is made anaerobic. After five days the bladder refueling valves are opened and the bladder can begin to take up the volume of biogas for 40 days. Every day, the weight of the product gas is weighed. The masses obtained enabled to establish the kinetics of biogas production. The physicochemical parameters of the digestate have been determined, and its fertilizing properties have been demonstrated. The digestate has been valued in agriculture in rice cultivation. The yield obtained was close to that of the control chemical fertilizers with yields of 675966 seeds in the surfaces treated with digestate and 689700 seeds in the surfaces treated with chemical fertilizer.

These results show that the production of biogas and digestate are valuable in energy, agriculture, refugee camps, probably in the restoration of abandoned mining sites and in the sanitation of prisons and villages.

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Table 3: Financial Review of the Design and Operation of the Biodigester

Materials	Number	Unit Price	Total Price
220 L Pvc barrel	1	25000frs	25000frs
Pvc hose Ø63	3m	1000	3000
Pressure valve	3	2500	7500
Pressure bend 16 males	1	2000	2000
Embossed to pressure 16 female	3	1000	3000
Compression hose 16	1m	1000	1000
Manometer	1	12500	12500
T of diameter 16	1	2000	2000
Necklaces	6	100	600
Grabbers	12	100	1200
Pegafor glue	One box	20000	20000
Super glus	50	100	5000
Glue aradite	20	1000	20000
Truck bladder	2	8000	16000
Can of 5L	3	1000	3000
Mixing pond	1	5000	5000
Biogas burner	1	15000	15000
Transportation costs of organic matter			15000
Total			156800frs

Table 4: Financial balance of laboratory analyzes

Analyzes	Number	Unit Price	Total Price
Nitrogen dosage	6 samples	6000	36000
Phosphorus dosage	6 samples	10000	60000
Potassium dosage	6 samples	10000	60000
Exchangeable bases	6 samples	20000	120000
pH	6 samples	1000	6000
Ec	6 samples	1000	6000
Humidity	6 samples	2000	12000
Determination of metals	6 samples	10000	60000
Total			360000
Total with discount			250000