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Design and Construction of an Experimental Biodigester in the Senkerfa Poultry Farm in Kankan, Guinea

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Abstract: This study is a continuation of our research work on the energy recovery of OM (Organic Matter) and the protection of the environment. It took place from October 1 to November 25, 2021 in the poultry farm of Mr. Elhadj Daye KABA in the Senkefra district, urban commune of Kankan. During this work, we designed, built and tested a 6 m^3 biodigester. Cow dung (2,500 kg) with 2,300 L of water served as a substrate for the production of biogas during 30 days of digestion. The following physico-chemical parameters: Temperature (T °C), Humidity (H%), Hydrogen potential (pH), Dry Matter (DM), Organic Matter (OM) and the ratio between Carbon (C) and Nitrogen (N) (C/N) of cow dung were determined, namely: T (28°); H (75%); pH (6.5); MS (15%); MO (55%) and C/N (25%). During the 30 days of digestion, the temperature varied from 27 to 35°C with an average of 30.57 °C (mesophilic digestion); the pH varied from 6 to 9, with an average of 7.58; the daily production kinetics represented the four stages of digestion (hydrolysis, acidogenesis, acetogenesis and methanogenesis). The cumulative production of biogas is 198 m^3. The composition of the biogas produced is 60% CH_4, 36% CO_2, 2% N_2, 2% H_2S and 1.5% H_2. The biogas produced was used for lighting, water heating and cooking. These results show that the biogas produced is of good quality and remains consistent with the literature.

Key words: Biodigester, biogas, design, farm, cow dung, Kankan.

1. Introduction

Anaerobic digestion is a natural process of biological degradation of OM (Organic Matter) in an oxygen-free environment (anaerobic digestion), due to the action of multiple microorganisms. It takes place in four stages (hydrolysis, acidogenesis, acetogenesis and methanogenesis), with different bacteria adapted to each of these stages [1, 2].

Biogas, with a CH_4 content ranging from 40% to 75% and CO_2 content from 25% to 50%, is one of the forms of renewable energy that has been exploited for several decades and is used as a substitute for fossil fuels [3, 4].

With ever greater and more diversified consumption all over the world, the production of waste continues to increase in quantity and quality, thus creating enormous risks for the environment and, consequently, for the health of the population. This situation is much more worrying in DCs (Developing Countries) due in particular to the considerable delay in the biotechnological field [5, 6].

The European Union has published a roadmap which aims to reduce GHGs (Greenhouse Gases) by 80%-95% by 2050. This should help limit the increase in global temperature to a maximum of 2 °C. To achieve this objective, the current fossil energy carriers must be replaced by renewable energies, such as biogas [7, 8].

In Guinea, organic waste generated mainly by agricultural and agro-industrial activities is traditionally recovered on site in soil fertilization as organic amendment and/or for energy purposes as fuel. With more than 70% of the rural population living mainly on agricultural and livestock products, less than 15% are connected to the national electricity grid,

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which has the negative consequence of deforestation through the use of wood as a source of energy [9].

Anaerobic digestion or anaerobic digestion is a process that is both old and new: Old because the natural phenomenon of fermentation into flammable gas in marshes was identified by VOLTA in 1776; New because the industrial implementation of this biotransformation dates back to the 1950s, for the digestion of sludge, and the beginning of the 1990s for waste [10].

In Guinea, research work on the construction of biodigesters began in 1977 with the construction of experimental digesters [11].

The rural populations of the administrative region of Kankan and just like all the other rural areas of Guinea, are confronted with a recurring problem of energy resources. However, the main activities of these populations are agriculture and animal husbandry. Animal manure generated by the livestock sector can be enhanced through methanation to produce energy and digestate for soil amendment [12, 13].

The general objective of this study is the design, construction and testing of a biodigester in Senkerfa, Kankan. The specific objectives pursued are: the sizing, the construction of the biodigester, the determination of the physico-chemical parameters of the substrate (cow dung), the monitoring of the evolution of the digestion parameters (temperature, pH, kinetics of daily and cumulative productions) and determination of the composition and use of the biogas produced.

2. Material and Method

2.1 Hardware

2.1.1 Presentation of the Study Area

The administrative region of Kankan is located 781 km from the capital Conakry. It is the largest administrative region of Guinea, it covers an area of 72,145 km², with five prefectures (Kankan, Kérouané, Kouroussa, Mandiana and Siguiri). The sub-Sudanian climate is characterized by the alternation of two seasons (dry and rainy) with temperatures varying from 25 °C to 41 °C and rainfall varying between 1,100 and 1,800 mm of water per year [14]. The population of the Kankan region is estimated at 2,097,257 inhabitants in 2016, with an average density of 28 inhabitants per km². The prefecture of Siguiri is the most populated in the region and in Guinea, with 724,631 inhabitants, including 360,147 women (49.70%) [15].

2.1.2 Equipment for the Design, Production and Testing of the Biodigester

The experimental biodigester was built in the poultry farm of Mr. Elhadj Daye KABA in the Senkefra district in the urban commune of Kankan on an area of 72 m^2. It includes: an inlet or feed basin, the digester (body of the digester), the dome, the manhole or manhole), the outlet basin, the compost pits and a piping network.

The main materials used for the construction of the biodigester are: cement, sand, gravel, PVC (Polyvinyl Chloride), Galba pipe, acrylic paint, neoprene pipe, tangite glue, valves, galvanized nipple, hambou and collars.

The materials for physico-chemical characterization of the substrate (cow dung) are: drying and calcination ovens, DIAL-O-GRAM brand analytical balance, glass stirrer, tongs, test tube, beaker, cylindrical container. The experimental materials consist of equipment and measuring devices, including: biogas lamp, stoves, burners, CL3020 multimeter, LANNEG manometer, pH-meter, chronometer.

2.2 Method

The methodology used for this study focuses on theoretical and practical approaches according to the different stages.

2.2.1 Design and Construction of the Biodigester

Since the biogas needs are known, the Hashimoto relationship makes it possible to determine the specific daily production of biogas (Eq. (1)) [16].

$$P_v = \frac{B_0 \times S}{\text{TRH}}\left[1 - \frac{K}{\text{TRH} \times \mu m - 1 + K}\right] \qquad (1)$$

The volume (V_D) of the digester is the volume of the whole formed by useful volume (V) and the gasometer (G), given by Eq. (2).

$$V_D = \frac{m(1+x)}{\rho_s}\left[\text{TRH} + \frac{B_0 . c . \rho_s}{\text{TRH}(1+x)}\left(1 - \frac{K}{\text{TRH} \times \mu m - 1 + K}\right)\right] \qquad (2)$$

where: P_v: Biogas production per m^3 of fermenter per day; S: Volume load; B_0: Methane production potential (determined in the laboratory); TRH = V/Q - Average hydraulic retention time of the effluent in the digester; K: Inhibition constant; $\mu m = 0.013(T) - 0.129$- Kinetic coefficient or daily growth rate of microorganisms. $Q = \frac{m(1+x)}{\rho_s}$: substrate flow; m: Mass of substrate; x: Ratio water and substrate; ρ_S: Density of the substrate; $S = \frac{m \times c}{V}$ - Volume load; c: concentration of OM in the substrate

2.2.2 Experimentation of the Biodigester

This phase covers the following operations: the physico-chemical characterization of the substrate (cow dung), the loading of the biodigester and the monitoring of the biomethanation parameters.

The gravimetric method was used to determine the following parameters: density, H (humidity), quantities of DM (Dry Matter), OM and MM (Mineral Matter) [17]. The volumetric method allowed us to determine the Organic Carbon (CO) and the Total Nitrogen (NT), respectively according to the French standard NF U 44-161 and by the Kjeldahl method [9]. The pH meter was used for pH determination.

The biodigester was loaded on October 14, 2021 from 10 a.m., with 2,500 kg of cow's mouth and 2,300 litersof water, i.e. a total volume of 4.8 m^3. Three days after loading, the level of the effluent in the outlet basin has increased by 40 cm, this is the start of biogas production. The parameters (temperature, pH, kinetic and cumulative productions) were monitored during the thirty (30) days of digestion. The Multitec 540 brand gas analyzer made it possible to determine the chemical composition of the biogas produced.

The rusting and the construction of the digester are carried out in accordance with the diagrams of Figs. 1 and 2. The markings of temperatures, the use of biogas (lighting, cooking) are given by the photos of Figs. 3-5.

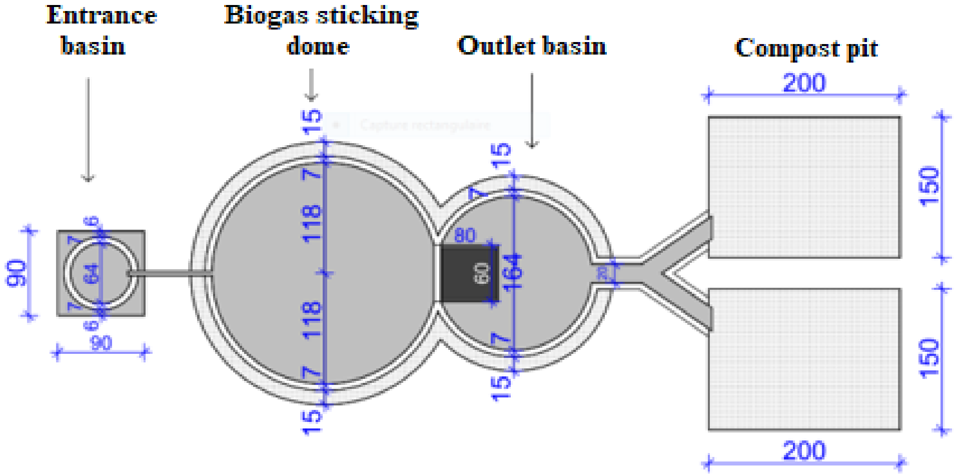

Fig. 1 Plan view of the biodigester.

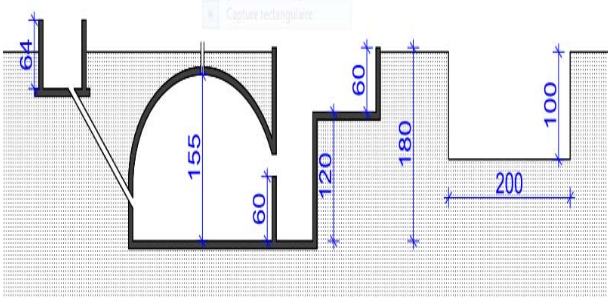

Fig. 2 **Sectional view of the biodigester.**

Fig. 3 **Biogas lamp on.**

Fig. 4 **Biogas combustibility test.**

Fig. 5 **Temperature measurement.**

3. Results and Discussions

The various results obtained during this research relate to: the geometrical parameters of the biodigester and its construction; the physico-chemical characteristics of cow dung; the evolution of the parameters (temperature, pH, kinetic and cumulative productions) of digestion and the composition of the biogas produced.

3.1 Geometric Parameters

The constructed biodigester is characterized by the following geometric parameters: (i) the inlet basin with a cylindrical shape with a radius of 32 cm and a height of 64 cm; (ii) the dome, in the shape of a spherical cap limited in its lower part by a flat circular surface with a radius of 118 cm, the horizontal circular surface at the bottom of the dome is separated from the biogas outlet hole by a distance of 155 cm; (iii) the outlet basin is 180 cm deep, it is divided into two parts: the first has the shape of a cylinder with a radius of 82 cm and a height of 60 cm; the second has the shape of a rectangular parallelepiped of dimensions 80 cm, 60 cm and 120 cm; (iv) the compost pit is a rectangular parallelepiped of dimensions 200 cm, 150 cm and 100 cm. The total volume of the built biodigester is 6 m^3, with a useful volume of 4.80 m^3 and that of the gas holder is 1.20 m^3, which corresponds to the daily production of biogas.

3.2 Physico-Chemical Characterization of the Substrate

The physico-chemical parameters of the substrate (cow dung) are: the H (Humidity Rate) is 75%, this result is between those found in Macenta and Boké, i.e. 64% and 82%. The pH of the initial substrate is 6.5, this value is relatively lower than those found in Mamou, i.e. 6.8 [9, 18, 19].

The rate of DM is 15%, this value is relatively lower than those found in Macenta and Boké, on the other hand it is consistent with that of other authors [20].

The OM rate is 55%, this value is relatively equal to those of Macenta, Boké and Parra et al. [21], i.e. 52%, 54% and 55%. The C (Carbon Content) is 45%. This value is in the range of carbon content favoring the increase and growth of microorganisms in the substrate, i.e. 20% to 70% [22].

The carbon and nitrogen (C/N) ratio is 25%, this ratio is in the optimal range for biogas production, i.e. 20% to 30%. These results show that the physicochemical characteristics of the substrate are different from one area to another, it says the way of life and the conduct of animals [23].

3.3 Digestion Parameters

The variations of the different digestion parameters (temperature, pH, kinetic and cumulative productions) are illustrated by the curves and diagrams in Figs. 6-10.

The curve in Fig. 6 shows the evolution of the temperature in the digester during 30 days of digestion. The digestion temperature varied from 27 to 35 °C with an average of 30.57 °C (mesophilic digestion) [24, 25]; in an ambient environment of 28.5 °C average temperature (Fig. 5).

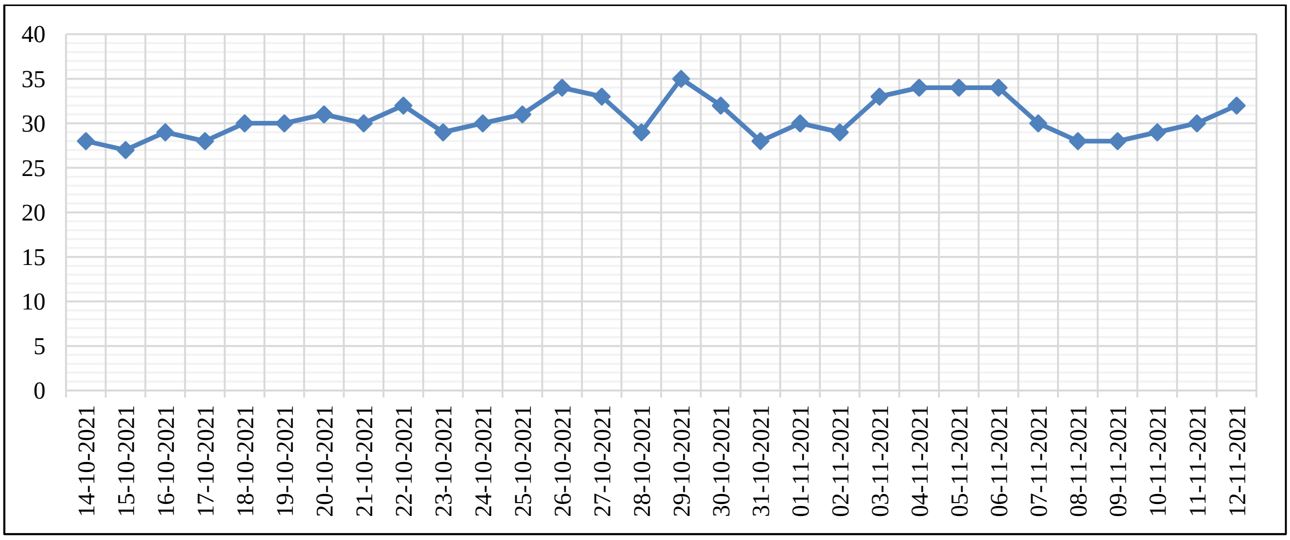

Fig. 6 Temperature evolution.

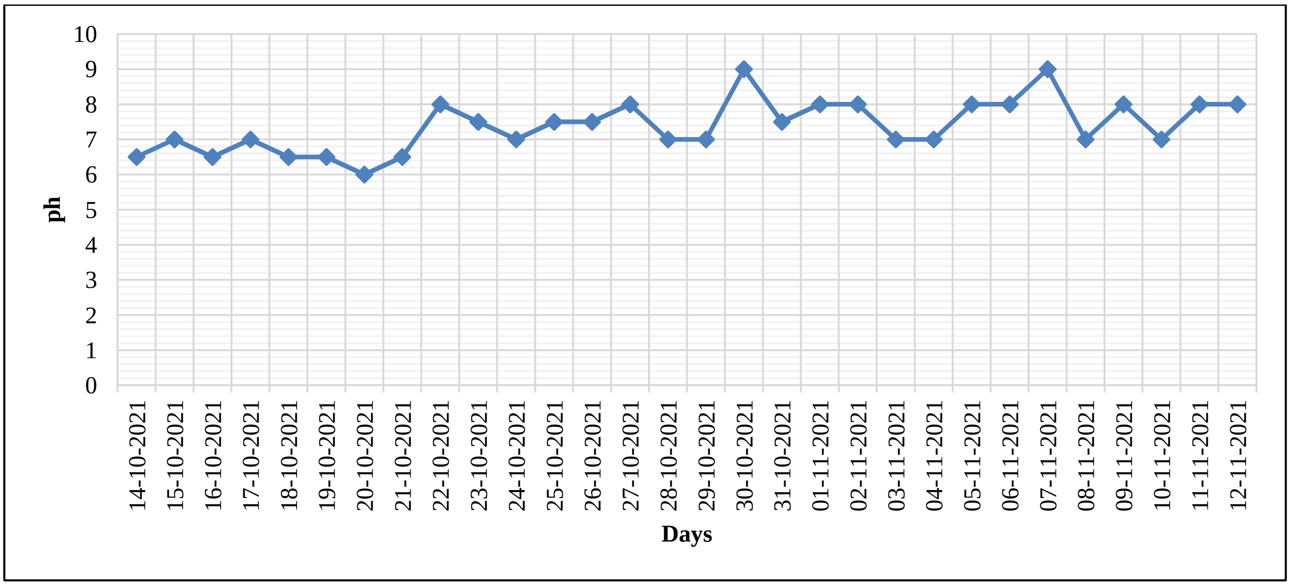

Fig. 7 Evolution of the pH.

The pH is an indicator parameter of the functioning of a digester. The optimum pH for anaerobic digestion is around neutrality, it is 6.8 to 7.5 [9]. The curve in Fig. 7 shows the evolution of the digestion pH, it varied from 6 to 9, with an average of 7.58; this value remains included in the development range of microorganisms for optimal biomethanation. Three phases are observed in the evolution of the pH during the digestion period, which are [23]: (i) the acidification phase, which is observed between the 1st and the 8th day of the load with values going from 7 to 6; (ii) the alkanization phase, which corresponds to the slowest pH evolution period, it occurs from the 8th to the 23rd day, with values varying from 6.5 to 8; (iii) the stabilization phase, it takes place from the 14th to the 30th day, with values of 7 to 9. These results remain consistent with those of Nkodi et al. [26].

The daily production kinetics are represented by the curve in Fig. 8. During the 30 days, with an average digestion temperature of 30.57 °C (mesophilic digestion), the daily production of biogas was not uniform. During the first two days (hydrolysis and acidogenesis phases) the production of biogas remained very low and therefore was not recorded. From the 3rd we recorded a production (0.1 m^3); it gradually increased with a maximum of 20 m^3 recorded on the 19th day. After the 19th day, we observed a decrease in production until the 30th day, for a minimum value of 0.1 m^3. This daily production kinetics remains consistent with the results in the literature by Jame et al. [27].

The cumulative biogas production curve is shown in Fig. 9. During the first week of digestion, biogas production remains relatively reliable, ie (1 m^3); then an acceleration of production to decline or slow down at the end. This kinetics is characterized by three phases (latency, exponential and plateau) [28].

The latency phase lasted 4 days with a production of 0.4 m^3. This period corresponds to the liquefaction phase during which hydrolysis, acidogenesis and acetogenesis take place [8]. In general, the duration of this phase depends on the nature of the substrate.

The exponential phase lasted 20 days, from the 8th to the 27th day; the maximum daily production of biogas was observed during this period, i.e. 20 m^3 on the 19th day. This phase corresponds to the central part of the cumulative production curve (methanogenesis phase) [9]. The plateau phase lasts 3 days from the 28th to the 30th day, with a low production of biogas under the effect of the depletion of the substrates [8]. During the 30 days of digestion of 2,500 kg with 2,300 litersof water, we obtained 198 m^3 of biogas.

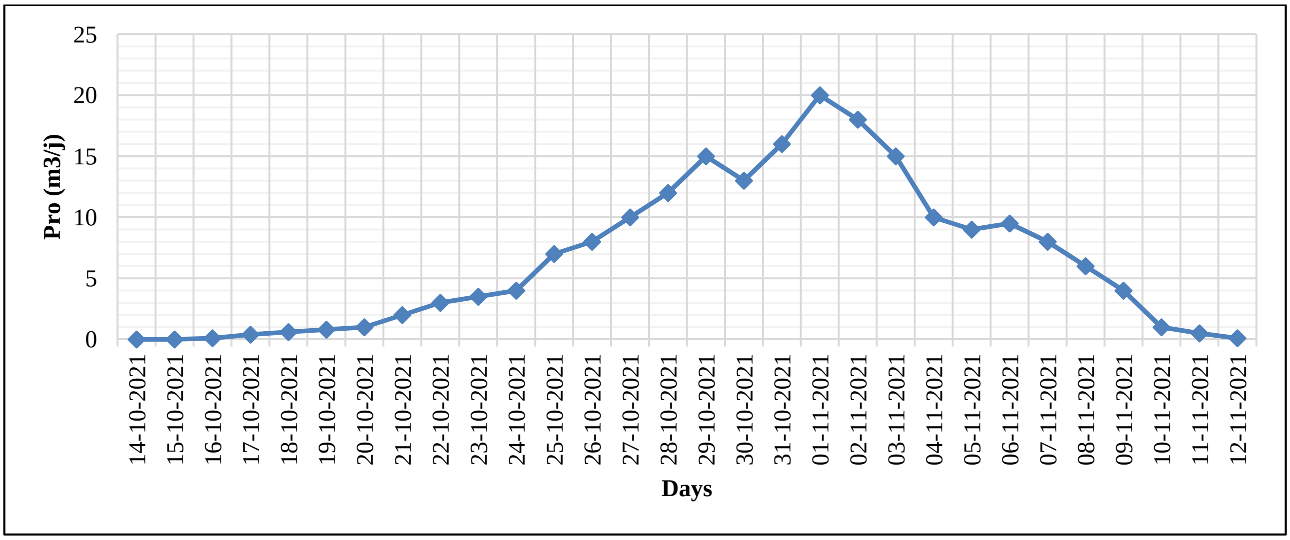

Fig. 8 Daily production kinetics.

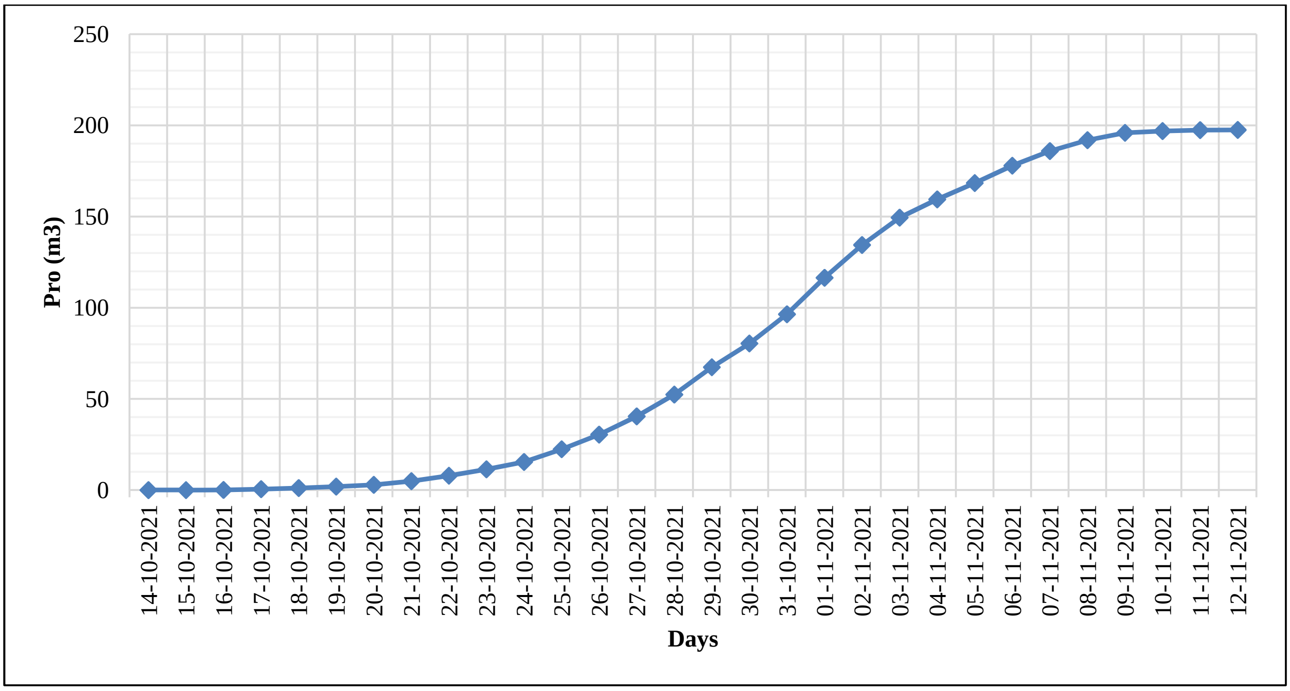

Fig. 9 Cumulative production kinetics.

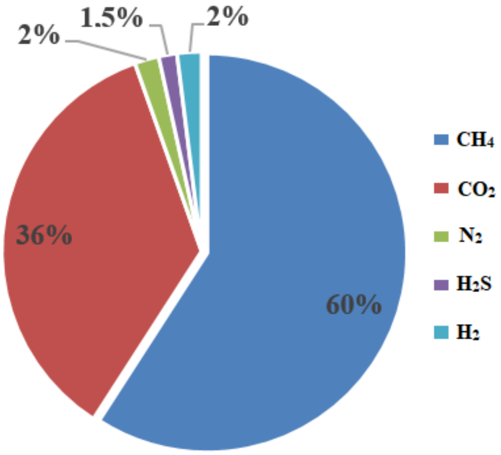

Fig. 10 Composition of biogas.

3.4 Composition of Biogas

The composition of biogas is illustrated by the diagram in Fig. 10.

The quality of biogas is determined by its methane content, the biogas produced is composed of 60% CH_4, 36% CO_2, 2% N_2, 2% H_2S and 1.5% H_2. These results show that the biogas produced is of good quality and remainsconsistent with the literature [29]. The biogas produced was used for lighting (Fig. 3), heating water and grilling the eggs (Fig. 5).

4. Conclusion

The production of biogas from various organic materials of plant and animal origin, industrial sewage treatment plants, household waste, etc. through the anaerobic fermentation process, allows better waste management, preservation of the environment and diversification of energy resources. Thus, research in this theme must be continuous, this present work which is part of this dynamic has made it possible to determine the physico-chemical parameters (DM, OM, density, humidity, pH and carbon and nitrogen contents) of cow dung. The design, construction and testing of a 6 m^3 biodigester have been carried out. During 30 days of digestion, the variations of the parameters (temperature, pH, kinetics of daily and cumulative production) were monitored. The composition of the biogas produced was analyzed (60% CH_4, 36% CO_2, 2% N_2, 2% H_2S and 1.5% H_2). The biogas produced was used for lighting and cooking. The continuation of biomethanization work remains a necessity for the protection of the environment and the local production of energy and organic fertilizers.

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