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# Recovery of Sludge through Biogas Production: The Case of the Urban Commune of Mamou (Republic of Guinea)

**Thierno Amadou Barry[1], Ansoumane Sakouvogui[1], Elhadj Ousmane Camara[1], Ibrahima Maciré Camara[2], Adama Moussa Sackho[2]**

[1]Institut Supérieur de Technologie, Département Energétique, Mamou, Guinée
[2]Department of Laboratory Chemistry Techniques, Higher Institute of Technology, Mamou, Guinea

Corresponding Author: Thierno Amadou Barry

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## ABSTRACT

In the cities of Guinea in general, and the urban commune of Mamou in particular, all households use sanitation systems that are not connected to a sewer network. These installations need to be emptied once they are full. Emptying services are provided by the urban commune's environmental and sanitation department, which has a 6 m³ truck, and by manual emptiers. The emptying of latrines and septic tanks is neither planned nor controlled.

The objective of this study is to valorize the sewage sludge produced in the urban commune of Mamou through biogas production in order to develop a safe management and reuse strategy. The methanization of sewage sludge to be disposed of is essential for organizing the collection service, sizing the treatment facilities, and assessing valorization methods.

Three (3) 4.5-liter plastic bottles were used simultaneously as digesters; these bottles were filled to three-quarters of their volume with two types of substrates and their mixtures. These samples were each diluted in 2.5 liters of water. During 25 days of experimentation, the following parameters and their values were observed: Internal temperature of the digesters (24 to 28°C) conducive to mesophilic digestion, optimal for the activity of methanogenic bacteria; external temperature (21 to 30°C) ensuring good thermal maintenance of the environment; pH of the medium (6.00 to 6.75) favorable for the development of methanogenic bacteria; Daily biogas yield: Fresh sludge: 1.136 liters per day; Concentrated sludge: 0.456 liters per day; Codigestion: 0.695 liters per day.

The conversion of emptying sludge into biogas represents a sustainable solution to: reduce environmental nuisances related to its storage; produce renewable energy (methane usable for cooking, lighting, or as fuel); valorize liquids within a circular economy framework.

***Keywords:*** Valorization, sludge from septic tanks, biogas production, Mamou.

## 1. INTRODUCTION

The sanitation needs of more than 2.7 billion people worldwide are met by non-collective sanitation systems, a figure that is expected to reach 5 billion by 2030. The rapid population growth and the increase in residential areas are raising the need for sanitation in developing countries [1].

The sanitation sector is a complex field that interacts with others, such as water supply, urban planning and housing, land administration, public health, environmental protection, etc.

Emptying sludge is a mixture of fecal matter, urine, and wastewater collected through decentralized sanitation systems or systems not connected to the sewer network. Their colors range from dark brown to black. Black sludge, or stabilized sludge, comes from dry latrines (traditional or improved latrines). Brown sludge, known as putrefied sludge, comes from septic tanks (public toilets or family latrines) that are emptied every year or every two (2) years [2].

In Guinea, the sanitation subsector is by far the least developed. Individual autonomous sanitation is almost the only method used, and two-thirds of households use latrines, mostly uncovered, for 44.4% of the population. These facilities consist of latrines or septic tanks. When they are full, their contents are most often emptied by manual emptiers who end up near homes with all the associated risks, or by vacuum trucks. These emptying services, essential for improving the quality of living conditions, are neither planned nor regulated by the authorities [3].

Sanitation encompasses all concerns related to the collection and treatment of liquid, solid, or gaseous waste (effluents) generated by residents and their activities, whether domestic or economic [4]. Methanization is a biological mechanism for the degradation of organic matter, aimed at producing biogas mainly composed of methane while reducing the toxicity and volume of waste. It is particularly important for the management and valorization of sludge from septic tanks. Whether concentrated or fresh, this sludge poses management challenges due to its volume, content of pathogenic organisms and greenhouse gases, as well as its environmental impacts [5]. The treatment of sewage sludge through methanization allows these wastes to be converted into a renewable energy source while minimizing their environmental impact. Depending on the origin of the sludge, its composition, the treatment objectives, and conditions, several approaches are possible. The methanization of concentrated or fresh sludge can be carried out alone, but co-digestion (the combination of these two types of sludge) improves the efficiency of optimal biogas production while also managing waste and reducing the nuisances associated with its storage [6]. As part of this study, the recovery through biogas production from sludge generated within the urban municipality of Mamou for the development of a management strategy; the methanization of sludge to be disposed of is essential in order to organize the collection service, size the treatment facilities, and assess the methods of recovery and/or reuse safely [7].

## 2. MATERIALS AND METHODS

### 2.1. Equipment

#### *2.1.1. Description of the study area*

Located 275 km from Conakry, the city of Mamou is located between 9°54′ and 11°10′ north latitude and 11°25′ and 12°26′ west longitude. It covers an area of 2,350 km² and has 81,992 inhabitants, for an average density of 35 inhabitants per km². It is made up of 28 urban and peri-urban districts, bounded: to the east by the sub-prefecture of Dounet; to the west by the sub-prefecture of Konkouré; to the north by the sub-prefecture of Boulivel; to the south by the sub-prefecture of Soya. Its climate is of the Foitanian type, characterized by the alternation of two seasons of equal duration: a dry season from November to April and a rainy season from May to October [8].

#### *2.1.2- Measuring tools and devices*

The study focused on determining the amount of biogas contained in 3 kg of each type of substrate (fresh cow dung and concentrated cow dung) and the mixture of the two substrates (Co-digestion) in the proportion of one and a half (1.5) kg of each type. The main tools used were: a) a motorized tricycle, wheelbarrows, plastic containers, shovels, buckets, sterilized gloves, masks, safety shoes, neoprene hoses (12mm), valves, washers, adjustable clamps, graph paper, pliers, Teflon tape, pairs of scissors, knife, glue, screwdrivers, a tape measure (for collection, transport, and construction of the biodigesters); b) the KMRY analytical balance, digital thermometer with probe, pH meter, electronic multimeter (devices used for sampling and monitoring biogas production parameters).

## 2.2. Methodologies

Three 4.5-liter plastic bottles were simultaneously used as experimental biodigesters; each bottle was filled to three-quarters of its volume with the two types of substrate and their mixture. These samples were each diluted in 2.5 liters of water. These three biodigesters were each connected to an empty bottle of the same size (gasometer) through 12 mm inner diameter flexible tubes.

a) Phase 1: The biodigesters (bottles) shown in the first image of Figure 1 were connected to each other with flexible 12 mm diameter pipes. The substrate is placed in the first digester, the second contains water, and the third is intended for collecting the water that represents the amount of biogas produced.

b) Phase 2: Image 2 of Figure 1 shows that, from the start of the methanation process, the substrate level rises in the first biodigester (bottle). Due to the pressure exerted by the gas produced, the water contained in the second bottle gradually decreases and moves toward the third recovery bottle. This displaced water is then measured and quantified throughout the Hydraulic Retention Time (HRT).

Photos 3, 4, 5, and 6 in Figure 3 show the main steps in setting up the experimental device. Photo 3 depicts the sludge sampling phase, carried out according to a substrate collection and preparation protocol. Photo 4 shows the assembly of the biodigesters, including the installation of the reactors and the verification of the system's seal. Photos 5 and 6 highlight the loading of the prepared substrates into the biodigesters as well as the experimental monitoring, marked by the observation and indirect quantification of the biogas produced during the Hydraulic Retention Time (HRT).

c) Biogas production: in accordance with the real gas law where $(V_0 - b)$, the volume of biogas produced is estimated based on the application of the equations of Van der Waals 1 and 2 [9, 10]

d)

$$P_1 + \left(\frac{a}{V^2}\right)(V_0 - b) = RT_1 \quad (1);$$

$$P_2 + \left(\frac{a}{V^2}\right)(V_0 - b) = RT_2 \quad (2)$$

Thus: $\Delta P = \frac{RT_1}{V_0 - b} - \frac{RT_2}{V_0 - b} = \frac{R}{V_0 - b}\Delta T$ (3)

Where: $a/V_0^2$ represents the internal pressure of the attractive forces acting between molecules,

b= The correction for the proper volume of molecules is equal to the volume of the molecules.

R=0,082 litter. atm/mol. K and T is the temperature in Kelvin (K). The volume of biogas produced, taking into account the conditions and the duration of the experiment, is given by equation 5.

$$V_{Biogaz} = (V_0 - b) \times \Delta n = \frac{\Delta P \times V_g}{T} \quad (5)$$

*e) Taux de dégyration du substrat*

The degradation rate of a substrate is determined by equation 6.

$$D_{sub} = \frac{V_{Biogas}}{V_{\boldsymbol{Theoretical}}} \times 100 \quad (6)$$

Figure 1 shows the steps of these methods used for the production of biogas from samples of two types of sludge: fresh sludge from septic tanks and concentrated sludge from dry latrines.

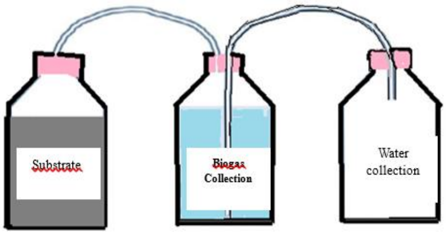


**Photo 1**: Biodigesters at the beginning of Retention Time

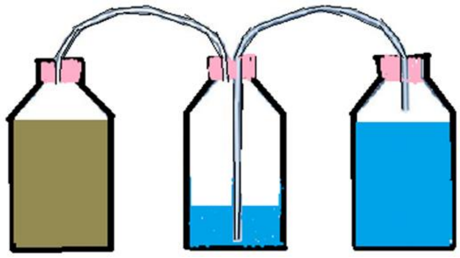

**Photo 2**: Biodigesters at the end of Retention Time

**Photo 3** : Waste sludge samples

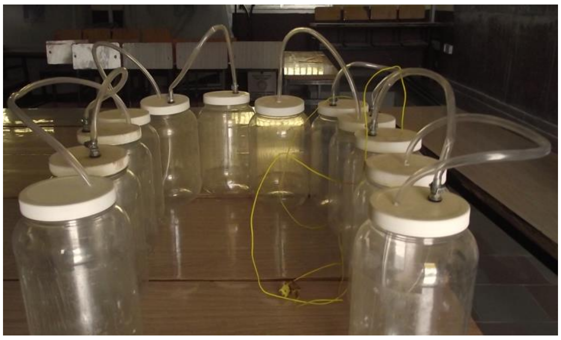

**Photo 4** : Unloaded digesters

**Photo 5**: Charged digesters connected to gasometers

**Photo 5**: Biogas produced 80% in biodigesters

**Figure 1** Steps in biogas production methods

## 3. RESULTS AND DISCUSSION

Table 1a showed the daily biogas production. During this experiment, the internal temperature of the biodigesters varied from 24 to 28°C, the external temperature of the biodigesters from 21 to 30°C, and the pH ranged from 6.59 to 7.40.

**Table 1** Biogas production from substrates

| N° | Date | Tex (°C) | Tin (°C) | pH | BF(BF) | (BC) | (BF +BC) |
|---|---|---|---|---|---|---|---|
| **1** | 27/12/2024 | 0,00 | 0,00 | 6,59 | 0,00 | 0,00 | 0,000 |
| **2** | 28/12/2024 | 25,25 | 24,83 | 6,59 | 0,28 | 0,00 | 0,000 |
| **3** | 29/12/2024 | 26,25 | 26,63 | 6,67 | 0,51 | 0,00 | 0,45 |
| **4** | 30/12/2024 | 25,00 | 26,50 | 6,72 | 0,72 | 0,05 | 0,70 |
| **5** | 31/12/2024 | 24,50 | 26,00 | 6,95 | 1,02 | 0,22 | 0,82 |
| **6** | 01/01/2025 | 26,25 | 26,00 | 7,00 | 1,20 | 0,23 | 0,95 |
| **7** | 02/01/2025 | 26,50 | 26,50 | 7,05 | 1,17 | 0,28 | 1,02 |
| **8** | 03/01/2025 | 26,00 | 25,00 | 7,08 | 2,34 | 0,33 | 1,12 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **9** | 04/01/2025 | 25,25 | 26,25 | 7,10 | 3,53 | 1,06 | 1,37 |
| **10** | 05/01/2025 | 25,25 | 25,25 | 7,17 | 4,14 | 0,56 | 1,55 |
| **11** | 06/01/2025 | 25,25 | 25,67 | 7,19 | 4,28 | 0,23 | 1,68 |
| **12** | 07/01/2025 | 25,75 | 26,00 | 7,20 | 4,82 | 0,16 | 1,81 |
| **13** | 08/01/2025 | 26,75 | 26,50 | 7,24 | 5,42 | 0,27 | 1,95 |
| **14** | 09/01/2025 | 25,50 | 25,00 | 7,24 | 6,87 | 0,99 | 2,21 |
| **15** | 10/01/2025 | 26,00 | 25,50 | 7,24 | 7,30 | 0,45 | 2,35 |
| **16** | 11/01/2025 | 25,25 | 25,50 | 7,26 | 9,97 | 0,26 | 2,91 |
| **17** | 12/01/2025 | 26,25 | 25,50 | 7,28 | 11,18 | 3,46 | 3,16 |
| **18** | 13/01/2025 | 24,50 | 25,25 | 7,30 | 11,36 | 4,29 | 3,45 |
| **19** | 14/01/2025 | 24,00 | 25,00 | 7,30 | 11,36 | 4,55 | 3,78 |
| **20** | 15/01/2025 | 24,50 | 23,67 | 7,30 | 11,36 | 4,56 | 4,20 |
| **21** | 16/01/2025 | 24,25 | 25,00 | 7,30 | 11,36 | 4,56 | 5,03 |
| **22** | 17/01/2025 | 24,00 | 24,50 | 7,35 | 11,36 | 4,56 | 5,37 |
| **23** | 18/01/2025 | 26,75 | 26,33 | 7,38 | 11,36 | 4,56 | 6,56 |
| **24** | 19/01/2025 | 24,25 | 25,75 | 7,40 | 11,36 | 4,56 | 6,95 |
| **25** | 20/01/2025 | 26,00 | 20,13 | 7,40 | 11,36 | 4,56 | 6,95 |
| **Averages** | | | | | **4,23** | **1,10** | **1,78** |

Te = External temperature of the biodigesters (°C); Tin = Internal Temperature of the Biodigesters (°C); BF = Volume of biogas produced by fresh sludge (L/day); BC = Volume of biogas produced by concentrated sludge (L/day); BF + BC = Volume of biogas produced by the codigestion of fresh and controlled sludge (L/day)

## 3.2. DISCUSSIONS

Figures 2, 3, 4 and 5 show the average biogas production kinetics of the two (2) substrates (fresh sludge, concentrated sludge, and their co-digestions) over a retention time of 25 days. The conversion into gaseous compounds (CO2 + CH4) of a defined amount of sludge (fresh and concentrated) occurs as follows:

a) For fresh sludge; the onset of biogas production after loading the experimental digesters was observed on the 2nd day, with fresh sludge showing a low production of 0.028 liters/day on the 7th day, then reaching a maximum of 1.136 liters/day on the 18th day and remaining stable until the 25th day (Figure 2). Fresh sludge exhibits very high production. This performance can be attributed to the presence of unaltered biodegradable organic matter, which promotes the activity of methanogenic microorganisms. The freshness of the substrate is a key factor in maintaining good biological activity [11].

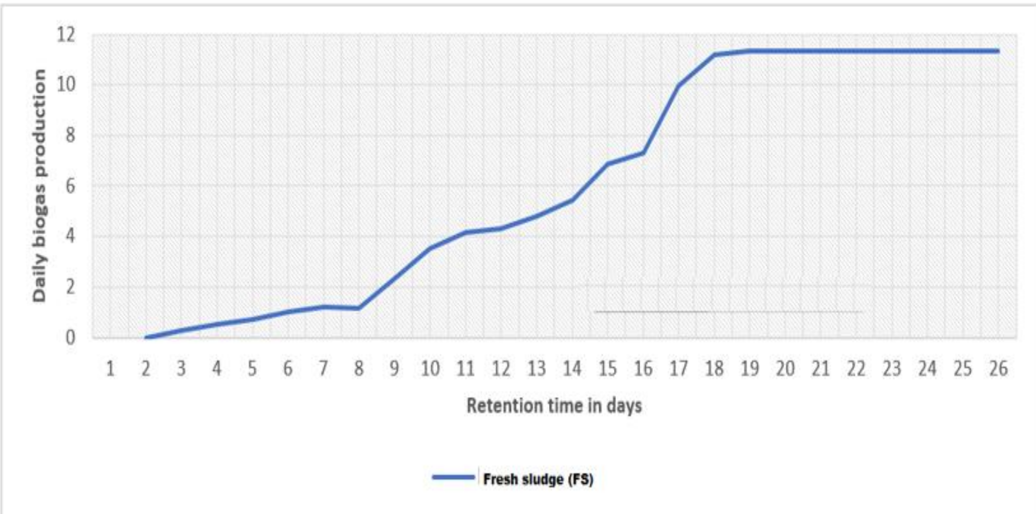


**Figure 2** Kinetics of biogas production from fresh sludge

b) For the concentrated sludge, the start of production was observed on the 3rd day with a very low production of 0.05 liters/day, on the 8th day, and production drops occurred between the 10th and 11th days from 0.23 to 0.16 liters/day, then between the 15th and 16th days from 0.045 to 0.026 liters/day, before reaching a maximum of 0.456 liters/day on the 23rd day and remaining stable until the 25th day (Figure 3). The concentrated sludge generated less biogas production due to a high concentration of non-biodegradable materials and the non-homogeneity of the substrate, which caused partial inhibition of the methanogenic bacteria.

c) For the codigestion of fresh and concentrated sludge, production began on the 3rd day with a very low output of 0.045 liters/day and reached a maximum of 0.656 liters/day on the 23rd day, then remained stable until the 25th day. The codigestion showed intermediate production. This substrate allowed for a synthesis between different types of materials, promoting process stability and more consistent production. However, the delay observed in reaching the peak (23rd day) could be related to a longer microbial adaptation phase due to the complexity of the mixture (Figure 4).

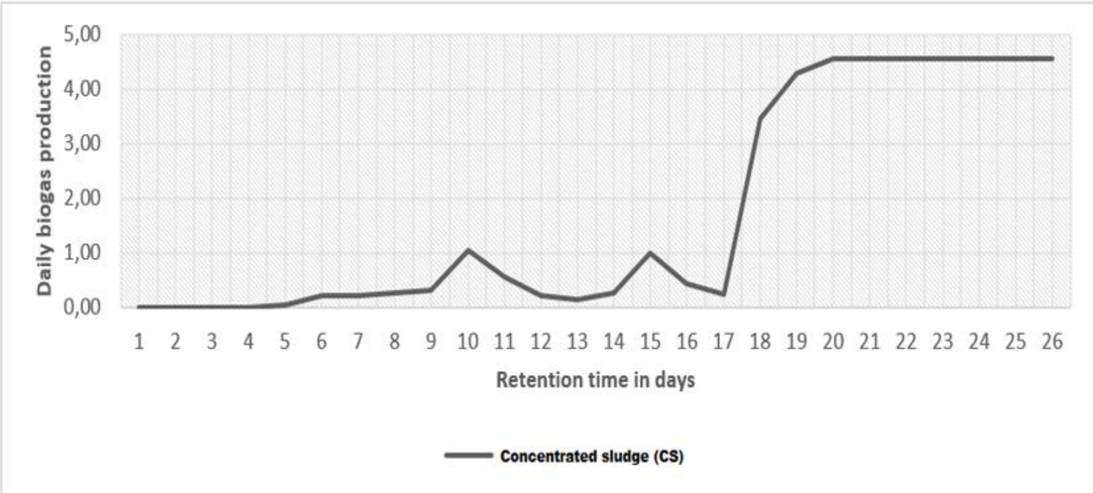


**Figure 3 Biogas production kinetics of concentrated sludge**

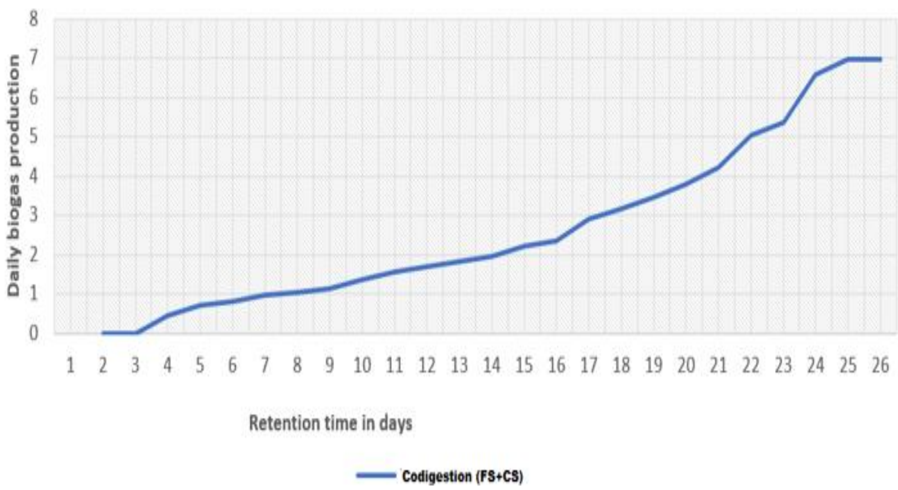


**Figure 4 Cinétique de production en codigestion du biogaz**

e) Figure 5 allowed for the observation of significant variations in daily biogas production depending on the substrates used. The blue curve shows that fresh sludge has a high yield, reaching a maximum of over 11 L around the 18th day, before stabilizing, indicating significant biodegradability and optimal methanogenic activity. In contrast, concentrated sludge does not exceed 5 L and shows an irregular pattern, marked by fluctuations, due to prior degradation of the substrate. However, the co-digestion of fresh and concentrated sludge shows a steady increase, reaching about 7 L on the 19th day, surpassing concentrated sludge from the 18th day onwards. This moderate progression reveals partial synergy between the substrates, promoting a relevant balance between production performance and methanogenic process stability [12].

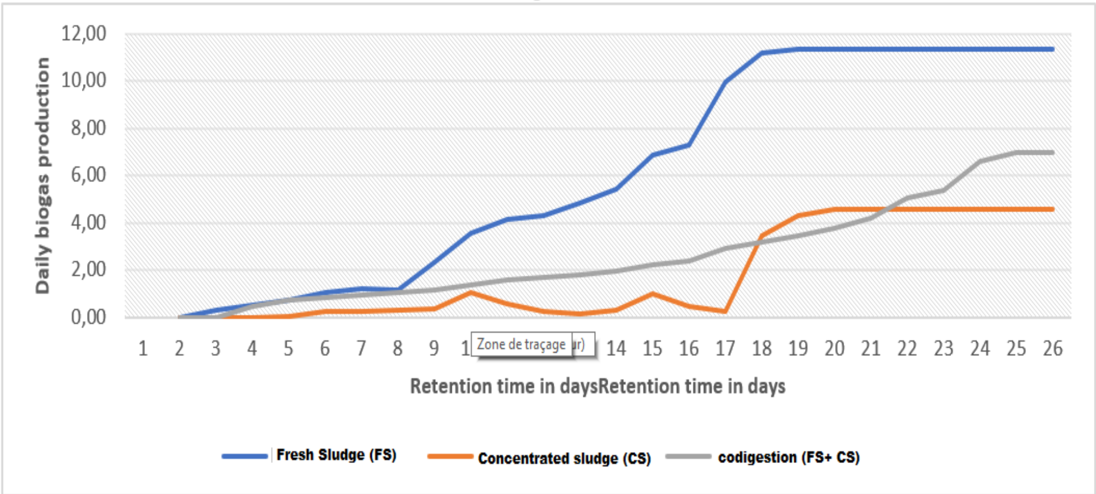


**Figure 5 Cumulative biogas production kinetics**

## 4. CONCLUSION

The energy recovery of sludge collected from autonomous sanitation facilities in different neighborhoods of the urban commune of Mamou allowed for experimenting with biogas production from fresh sludge, concentrated sludge, and their co-digestion.

During the 25-day retention period, the observed experimental conditions were: the internal temperature of the biodigesters ranging from 24 to 28°C, the external temperature of the biodigesters ranging from 21 to 30°C, and the pH ranging from 6.59 to 7.40, with 1.136 liters/day of fresh sludge, 0.456 liters/day of concentrated sludge, and 0.695 liters/day of co-digested fresh and concentrated sludge.

These sewage sludges, often considered waste, have an interesting methanogenic potential when properly characterized and treated. Their organic matter content and carbon/nitrogen ratio are compatible with efficient anaerobic digestion. Combining these two types of sewage sludges in experimental biodigesters has improved process stability and increased biogas production. The results showed that fresh sludges are the most productive. This process offers a sustainable solution that is ecological, economical, and adapted to local realities, helping reduce sanitary and environmental nuisances associated with the management of liquid waste in the urban community of Mamou.

***Declaration by Authors***

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**Conflict of Interest:** No conflicts of interest declared.

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