

Biogas Refining for Better Physicochemical Characteristics and Good Yield

Haroun Ali Adannou^{1,2}, N'Gueassembaye N'Gambainan¹, Dingammadji Richard¹

¹Department of Physics and Chemistry, Higher Normal School of N'Djamena, N'Djamena, Chad

²African Laboratory for Sustainable Development Research, N'Djamena, Chad

Email: harounali100@Gmail.com

How to cite this paper: Haroun, A.A., N'Gambainan, N. and Richard, D. (2024) Biogas Refining for Better Physicochemical Characteristics and Good Yield. *Natural Resources*, 15, 255-272.

<https://doi.org/10.4236/nr.2024.1510016>

Received: September 14, 2024

Accepted: October 28, 2024

Published: October 31, 2024

Copyright © 2024 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution-NonCommercial International License (CC BY-NC 4.0).

<http://creativecommons.org/licenses/by-nc/4.0/>



Open Access

Abstract

The general objective of this present work is to refine biogas in order to use it in an engine to produce electricity. The specific objective is focused on the availability and creation of energy, environmental protection, and the provision of biofertilizers to name a few. We worked on industrial applications and data for two years. The calculation methods and the most important parameters measured and observed during the work with various types of equations and monitoring, such as the search for the useful volume of the digester, the retention time, the organic load rate, the daily production of biogas, and the technological yield were made. The biogas produced was refined following the standards and purification procedure and the presence of H₂S brought back to a ppm lower than 200. To better characterize our biogas, a weekly, monthly and annual monitoring was done. The aim of this monitoring was to understand the production curve and bring technological elements of positive change by working on the pH, the temperature, the ratio and inhibitors. Thus, at the beginning, at 25 °C and 1 atm, the 6 gas molecules had a volume of 146.61 liters, so for 1 g of COD consumed, there was 0.7636 L of gas with 50% CH₄ and 50% CO₂. We therefore sought to make this result higher with a biogas rate of 60% CH₄ and 40% CO₂. It is observed that the values can vary by ±10% (sometimes more) depending on the implementation conditions.

Keywords

Digester, Refined Biogas, Purification, Technological Efficiency, Electricity

1. Introduction

The role of renewable energies in developing regions is not only to provide energy power but also to adapt to decentralized electricity production. They can help solve

several problems, including energy dependence and waste management, coupled with respect for the environment. As for the choice of biogas, it should be remembered that the energy value of a cubic meter of biogas corresponds to 0.42 kg of liquefied petroleum gas, 4.34 kg of dry wood, 0.6 liters of oil and 5 - 6 kWh of thermal energy, but also the destruction of many pathogenic germs, the elimination of odors from animal and human excrement, and the protection of runoff and groundwater. In addition, a cubic meter of effluent corresponds to 10 kg of ammonium sulfate, 4.5 kg of super-phosphate, 10 kg of potassium sulfate and other fertilizing elements [1]-[3]. It is recognized as the most energy-efficient and environmentally friendly [4] and allows the local level to produce energy at a lower cost for cooking, heating, lighting and organic fertilizers for better fertilization of crop soil [5] [6]. In our context, biogas is used as green energy and to do so, it must be refined to be used well in engines to produce electricity. To this end, it is important to report that wind, photovoltaic, solar thermal, hydraulic, solid biomass, geothermal, marine energy, and biofuels [7] are all natural resources that can be used to generate electrical energy, thanks to the different technologies that can be grouped by economic sectors depending on the resource considered. Available in quantities greater than the current energy needs of humanity, renewable energy resources do not increase the amount of greenhouse gases in the atmosphere during their exploitation. They also represent an opportunity for more than two billion people living in isolated regions to access electricity, thereby promoting the development of renewable energies [8]. For our study, as highlighted above, biogas is characterized firstly by its chemical composition and the physical characteristics that result from it. It is essentially a mixture of methane (CH_4) and inert carbon dioxide (CO_2). However, the name "biogas" includes a wide variety of gases resulting from specific treatment processes, from industrial, animal, household organic waste, etc. An important question about the course and natural preparation of this biogas is answered by the fact that: Anaerobic digestion is none other than the exploitation by man of a natural process, the methanogenic fermentation of organic matter, that is to say a fermentation with (bio) methane as the final electron acceptor. This degradation of organic matter in anaerobiosis leads to the formation of a gas mixture composed essentially of methane (CH_4) and carbon dioxide (CO_2). There are also many trace compounds (organic and inorganic) such as hydrogen sulfide (H_2S), thiols (= mercaptans) and a whole range of Volatile Organic Compounds (VOCs) (notably in biogas from waste storage facilities) commonly called biogas. Concerning the use of biomethane, historical evidence suggests that in 10 centuries BC, the Assyrians used it to heat their bath water [9]. Anaerobic digestion is therefore a natural biological process that occurs spontaneously in all ecosystems where organic matter is found in the absence of oxygen, and where the physicochemical conditions are compatible with those of living things [10] involving different microbial communities in the degradation and conversion of polymers of organic matter into reduced end products, including a biogas with high energy value [11]-[14]. In the following lines, we will explain in detail the methodology

of biogas refining and later, we will give the results of our research, which will be discussed at the same time.

2. Material and Method

In this part, we describe the working methods carried out daily as well as the materials used for the latter.

The feeding function of the pilot reactor in continuous operating mode will be presented by a principal diagram. We then define the calculation methods and the most important parameters measured and observed during the work. These parameters will be defined with various types of equations among which we will have the search for the useful volume of the digester, the retention time, the organic load rate, the daily production of biogas, and the technological yield. After production, we will present the characteristics of the biogas measured according to the analysis of the major gases CH_4 , CO_2 and H_2S .

2.1. Experimental Device

We illustrate our experimental setup with the following diagram:

The biodigester receives effluents composed of slaughterhouse waste (rumen content, blood and wastewater). The mixture is introduced into Compartment 1, which is the biodigester. After a defined time, the biogas is produced, and it is sent to the refining process (Compartment 2). From this process, the injected raw biogas is purified to remove any impurities to make it cleaner for the next system. Compartment 3 is a generator using biogas as fuel. It is a cogeneration system that produces heat and energy.

The entire system is controlled in a control room through the various sensors connected to it (Compartment 4).

Figure 1 gives us an overview of the architecture of our facility.

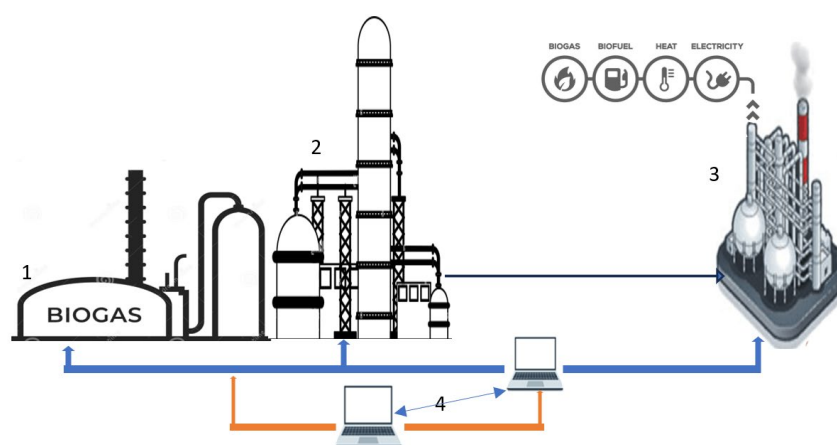


Figure 1. Diagram of the pilot device reduced to the bare minimum.

In this model, the principle is made easier for simple reading:

- 1) Biodigester producing raw biogas;

- 2) Crude biogas refining system;
- 3) Transformation and production of heat and energy for the consumption of the plant;
- 4) Control system linking physicochemical parameters of remote control and maintenance.

Analysis of major gases CH₄, CO₂ and H₂S

A portable multi-gas measuring device was used for its simplicity and reliability. It allows to know in real time the quality of the biogas analyzed in the field.

The biogas conversion is carried out in a synchronous PCCE consisting of a six-cylinder MAN gas engine, coupled with a Newage-Stamford generator with a rated power of 100 kW at 1500 rpm.

For the refining pole, the biogas thus produced is transported by a gas pipeline network to the refining unit, which is essentially composed of a desulfurization unit.

Two mixers prevent the substrates introduced into the tarpaulin from turning into a thick paste.

2.2. Working Methodology

2.2.1. Feeding the Pilot Reactor in Continuous Operating Mode

In normal operation, the reactor is fed 5 - 6 times per week following this procedure:

- Introduction of the biomass and grinding of the solid matter by the mixer);
- Introduction of the waste water using the pump, pre-mixing and homogeneous mixing by the pump;
- Introduction of the mixture into the digester;
- Withdrawal of a predefined quantity of the digestate at temperatures between 30°C and 80°C.

2.2.2. Calculation Method

1) Search for the useful volume

The useful volume of the digester (V_d) is calculated from the retention time (Tr) multiplied by the volumetric loading rate of substrate on a daily basis (Q), according to the equation:

$$V_d = Tr \times Q \quad [m^3 = \text{nombre de jours} \times (m^3/\text{jour})] \quad [15] \quad [16].$$

Furthermore, the digester volume is also a function of the concentration of organic matter in the substrate So and the organic loading rate (ORL), in terms of volume:

$$ORL = \frac{Q \times So}{V} = \frac{So}{Tr} \quad [(m^3/\text{jour}) = m^3/\text{number of days}]$$

2) Retention time

The retention time Tr represents the average residence time of the substrate (liquid or solid) in the digester. It generally lasts between 20 and 50 days [16] [17].

In general, a Tr of 20 days and more will be required for an efficient anaerobic

treatment process at a temperature near 30°C while this Tr will be much higher for lower temperatures [18]-[20].

$$\text{Tr} = \frac{V}{Q_f}$$

where Tr: Retention time; V: Volume of the anaerobic digester (m³); Q_f: Flow rate of the fresh substrate introduced (m³/day).

3) Hydraulic retention times

$$\text{TRH} = \frac{V_l}{Q_l}$$

where TRH: Hydraulic retention time (d); V_l: Volume of liquid in the anaerobic digester (m³); Q_l: Liquid discharge flow rate at the outlet of the anaerobic digester (m³·day⁻¹).

4) Solid retention times

$$\text{TRS} = \frac{M_s}{F_l}$$

where TRS: Solids retention time (d); M_s: Mass contained in the anaerobic digester (kg); F_l: Mass flow at the outlet of the anaerobic digester (kg·day⁻¹) [21] [22].

5) Daily organic load

$$C_{oq} = \frac{Q_f \times X_f}{V}$$

where C_{oq}: Daily organic load (kg·COD·day⁻¹ or kg·SV·day⁻¹); X_f: Concentration of the substrate in pollutant load (kg·COD·m³ or kg·SV·m³).

6) Applied volumetric load

The applied volumetric load (AVC) is expressed as the amount of volatile matter per unit volume of digester per day (kg_{MV}·m⁻³·j⁻¹). These two parameters are directly related to the volume of the digester used as indicated by the following adapted equations [23] [24].

$$\text{CVA} = M_V \times \frac{Q}{V}$$

where V: Digester volume (m³); Q: Daily flow rate (m³·d⁻¹); M_V: Volatile matter content (kg·m⁻³).

a) Daily biogas production

It is calculated from the specific daily biogas production (G_y) for a given substrate, and the quantity of this substrate supplied per day to the digester, *i.e.* the loading rate (Q) expressed in terms of mass.

$$G = G_y \times Q \quad [\text{m}^3/\text{jour} = (\text{m}^3/\text{kg}) \times \text{kg}/\text{day}]$$

b) Technological efficiency

The volumetric production of biogas or technological efficiency (G_p) corresponds to a daily production of biogas (G), per unit of digester volume (V_d).

$$G_p = \frac{G}{V_d} \text{ [(m}^3\text{/day)/m}^3\text{ digester]}$$

c) Performance assessment

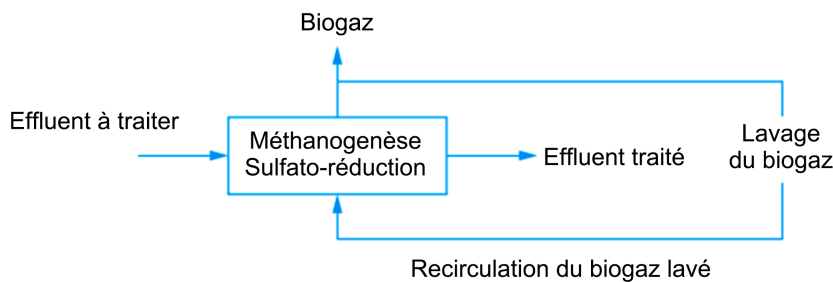
The performance is compared with the theoretical or experimental methanogenic potential, which represents the value of CH₄ produced per unit of volatile matter (VM) according to the substance [25] [26].

Bernet and Buffière (2008) [14] propose that the performance for solid substrates can be calculated from:

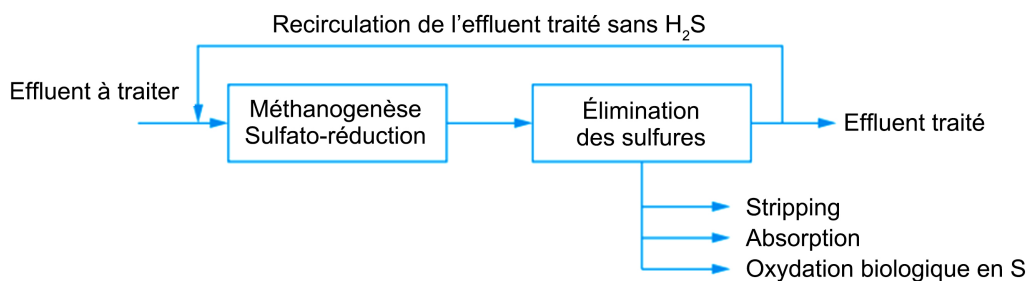
$$R_{\text{CH}_4} = \frac{Q_{\text{CH}_4}}{Q_e \times [MV]}$$

where R_{CH_4} : Methane yield (Nm³·kgMV⁻¹); Q_{CH_4} : Daily methane flow (Nm³·d⁻¹); Q_e : Daily sludge mass flux (kg·d⁻¹); $[MV]$: Fraction of MV in sludge (%).

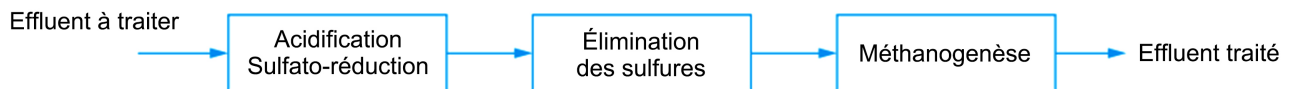
3. Result and Discussion



(a) stripping du H₂S par recyclage du biogaz (dans ligne gaz)



(b) élimination du H₂S par post-traitement (micro) aérobie et recirculation de l'effluent traité



(c) pré-acidification et sulfato-réduction combinées avec élimination des sulfures pour diminution des teneurs de S dans le méthaniseur

Figure 2. Effluent purification process by stripping and H₂S elimination. (a) Stripping of H₂S by recycling biogas; (b) Removal of H₂S by (micro)aerobic post-treatment and recirculation of the treated effluent; (c) Pre-acidification and sulphate-reduction combined with sulphide removal to reduce S concentrations in the anaerobic digestion plant.

In its composition, the biogas produced contains hydrogen sulfide (H₂S) which must be reduced to an infinitely small level (a few PPM) so as not to affect the correct operation of the electricity production center but also not to poison the users. This is done by introducing a few liters of air (6% of the total volume) using two compressors operating alternately. The role of these compressors is to regulate the system in the event of an excessive presence of H₂S by sending air to maintain a ppm below 200. They blow the air into two different places to have a homogeneous mixture meeting the desired standards. This H₂S management system involves oxidation-reduction reactions that transform H₂S into sulfate, oxygen and water. To be sure of this result, the gas produced is regularly analyzed to ensure that its composition is of quality.

Figure 2 shows the result of an effluent to be treated. In **Figure 2**, the effluent to be treated will undergo several operations in order to be treated.

Another result of the operation of the biochemistry pole is biofertilization: The operation of the biochemistry pole will lead to the degradation of the substrates introduced into the digester. To ensure the balance of the functioning of the bacteria, the substrates will be introduced every day and 80% of the equivalent of the substrates (in volume) will be removed. The products removed are called digestates and have a good agronomic value for plant fertilization.

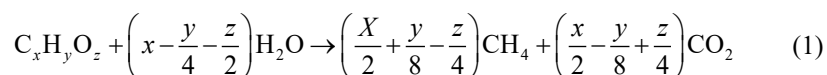
3.1. Result of Biogas Refining for Better Quality

Analysis of Major Gas Content

1) Theoretical biogas production

The theoretical volume of biogas produced can be estimated from Buswell's stoichiometric Equation (1), based on knowledge of the chemical composition of the substrate used:

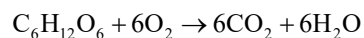
This Equation (1) can be rewritten by simplifying the term to obtain the same equation:



In Equation (1), C_nH_aO_bN_cS_d represents the chemical formula of the substrate subjected to anaerobic digestion, the production of methane being considered stoichiometrically maximum, it is simplified here with C_xH_yO_z while knowing that there is the presence of the elements NcSd.

We can evaluate the theoretical quantity of biogas formed during methanization.

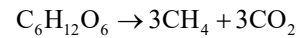
If we consider that the COD of a glucose molecule can be calculated from the following equation:



We have 180 g of glucose, which is theoretically oxidized by 192 g of oxygen.

This leads to a value of 192 g of COD.

If we neglect the biomass formed, a molecule of glucose is theoretically transformed into methane and carbon dioxide by the following stoichiometric equation:



We therefore obtain 6 moles of gas.

At 25°C and 1 atm, the 6 molecules of gas will have a volume of 146.61 liters, so for 1 g of COD consumed, we will have 0.7636 liters of gas with 50% CH₄ and 50% CO₂.

In reality, there is always a deviation from the theory, the quantity of biogas recovered is therefore less, and this is for several reasons:

1) The CO₂ produced is found in several dissolved forms CO₂d, HCO³⁻, H₂CO₃, CO³⁻.

2) The proportion of each of them varies depending on the physicochemical conditions (pH, salinity, temperature, type of effluent, etc.).

3) The composition of biogas is generally 60% CH₄ and 40% CO₂. These values can vary by ±10% (sometimes more) depending on the implementation conditions. A digester operating at basic pH will very easily have higher CH₄ contents than usual.

In the theoretical analysis of our data, we will see that the quantity of biogas produced by the biodigester respects this interval.

A portable multi-gas measuring device was used for its simplicity and reliability. The compounds detected are: CH₄, CO₂, O₂ and H₂S. The device operates over temperature ranges from -10°C to +40°C. It allows to know in real time the quality of the biogas analyzed in the field. Then, the biogas produced must be purified [27]. **Table 1** provides information on the quality of the average content of raw and refined biogas.

Table 1. Characteristics of the biogas content obtained.

Major gas	Variation of average content	
	Raw biogas	Refined biogas
CH ₄	54% - 74%	56% - 75%
CO ₂	16% - 28%	16% - 26%
O ₂	0.2% - 5%	0.0% - 3.6%
H ₂ S	0.11 - 360 ppm	≤2 ppm
Presence of traces of other matter		
H ₂ O	<1%	-
N ₂	<1%	-
NH ₃	<1%	-
H ₂	<1%	-
OTHER	<1%	-

These results are highly acceptable and allow the production of electricity and heat through a cogenerator.

The following figures (**Figure 3** and **Figure 4**) give us an overview of the simulation of the monthly production made for the first year and that of the second year.

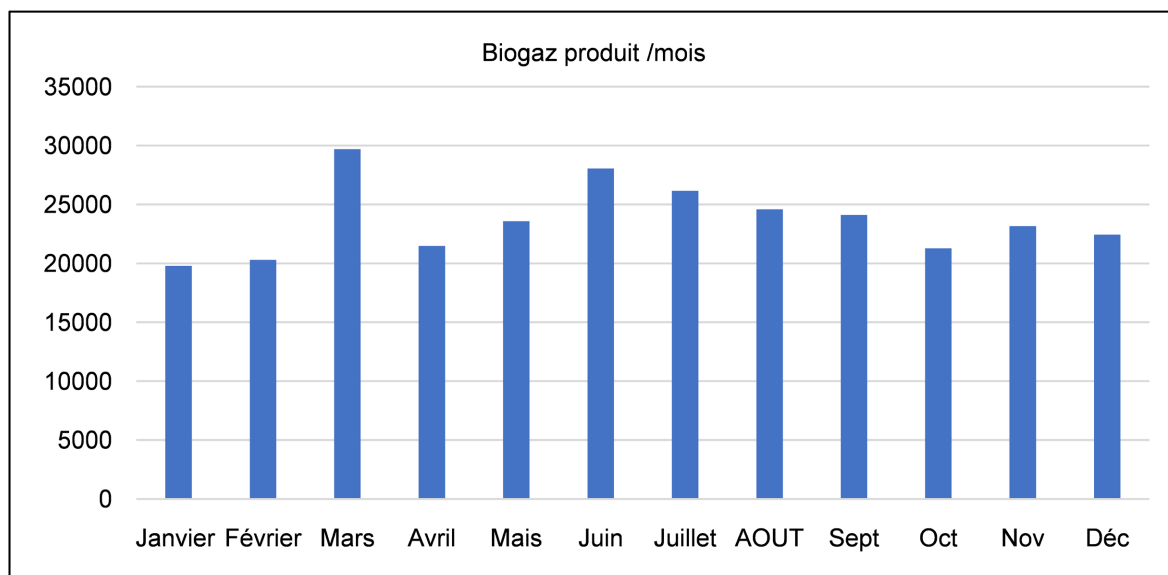


Figure 3. Simulation of monthly biogas production in the first year.

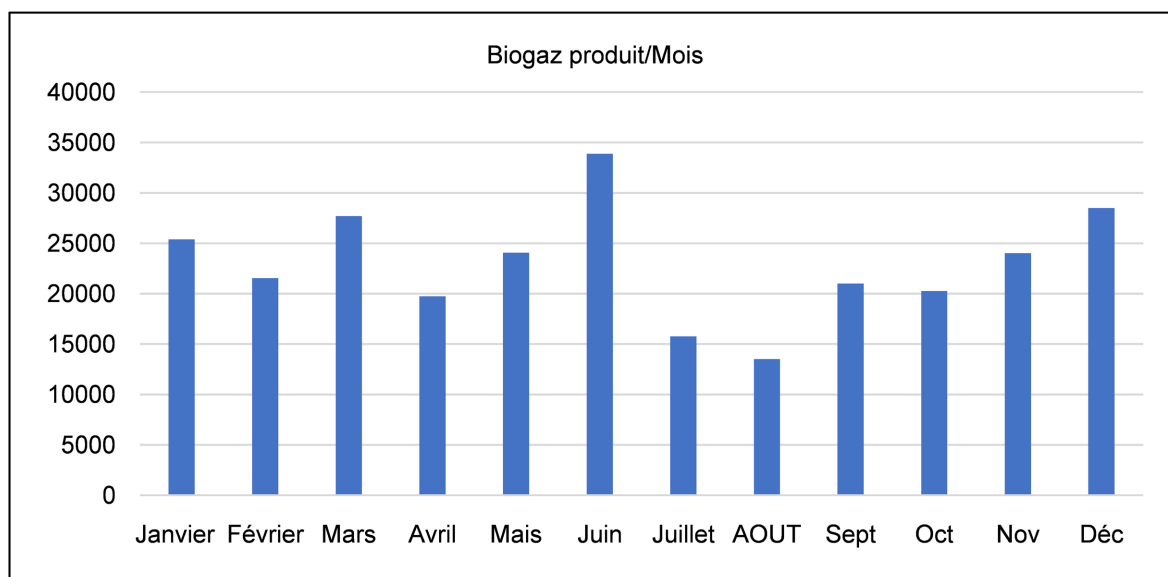
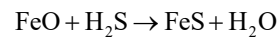
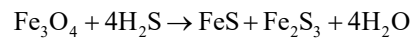
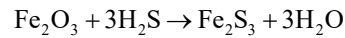


Figure 4. Simulation of monthly biogas production in the second year.

Biogas treatment aims to satisfy two processes for better purification. The first is to eliminate toxic and corrosive compounds, and the second aims to increase the proportions of methane to improve the energy properties of the gas mixture. The purification of our biogas follows the following reactions [28]:



2) Biogas treatment

Refining is the action of purifying a material in order to make it usable and/or marketable. The production of biogas with characteristics close to those of natural gas necessarily requires the combination of treatment and purification stages.

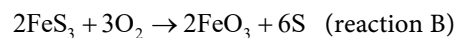
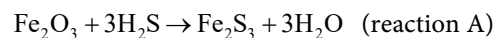
This stage is essential, while increasing the methane content of biogas depends on the chosen recovery method because untreated biogas contains on average 50 to 75% methane, which is too little for its use, but it can power engines or cogeneration installations. The biogas produced in digesters mainly contains methane and carbon dioxide. It may also contain other gaseous compounds depending on the type of effluent treated. These compounds are: H_2S , H_2 , NH_3 , CO , and the presence of water.

This may require treatment to remove molecules that could create problems (water or H_2S to avoid corrosion) or to remove molecules present that do not contribute anything to its recovery before storage (such as CO_2). The physicochemical treatment techniques used depend on the molecules to be eliminated.

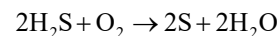
- To eliminate water, condensation techniques are applied to trap the droplets or drying with water vapor (cooling and trapping of water, adsorption on silica-gel type products, drying with glycol.
- Hydrogen sulfide can be removed from the biogas or its formation can be prevented.

For this, biological or physicochemical methods are available.

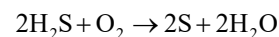
Among the latter, we will note the absorption of iron oxide particles (reaction A), which will be regenerated by oxygen (reaction B), absorption in liquids (diluted sodium hydroxide solution, iron chloride solution), or the use of separation techniques such as membranes and molecular sieves.



Biological techniques achieve the reaction:



A controlled supply of oxygen into a biological reactor that treats biogas leads to the following H_2S oxidation reaction:



With this approach, the H_2S content can be reduced to values of 20 to 100 ppm and removal efficiencies of 80% to 99% can be obtained.

However, biogas purification is mainly based on ex-situ physicochemical techniques [29]-[31], and biological techniques [32]-[34].

Table 2 provides a summary of the available technologies for biogas purification. This table provides information on the compounds to be eliminated as well as the techniques used for this exercise.

Table 2. Biomethane purification techniques according to Jonathan Hess.

Compounds to be eliminated	Techniques
Water	Condensation or cryogenics, absorption on glycols, molecular sieves
Sulfur	Pressurized water washing, adsorption on activated carbon,
Organohalogens	<i>In-situ</i> addition of iron chloride, biological techniques, micro-aeration
CO ₂	Activated carbon adsorption

3.2. Description of Biogas Purification Technologies

1) Elimination of dihydrogen sulfide

The dihydrogen sulfide present in biogas comes from the degradation of proteins and other sulfur-containing compounds. This corrosive gas must be removed from the biogas to preserve compressors, storage tanks and recovery equipment [35].

Washing can be done with water (the simplest solution) or with polyethylene glycol, in which the solubility of H₂S is higher.

First, the H₂S is solubilized in water to form sulfur ions S²⁻. These ions then react with ferric compounds (beads, wood chips covered with iron particles), and are oxidized to sulfur S.

The biogas is pressurized to increase its solubility, then injected at the bottom of a column containing the solvent, and the purified biogas is recovered at the top of the column. Once saturated, the solvent can be regenerated either by lowering the pressure or by bubbling air inside [36]. Adding soda to the washing water increases the solubility of the gases, and the soda reacts with dihydrogen sulfide to form sodium sulfate; in this case, the absorption is partly chemical. These physical and chemical methods only remove H₂S from the biogas, but do not convert it into a valuable product, unlike ferric reduction, which converts dihydrogen sulfide into sulfur [37]. Injecting oxygen into the medium then regenerates the ferric compounds, and sulfur is ultimately recovered.

2) Elimination of water vapor

Water vapor is a barrier to biogas valorization at several levels; it can react with H₂S and form a corrosive acid, but it also risks condensing or even freezing if the gas is compressed for storage [38], and it is essential to dry the biogas. This can be done by condensation by cooling the pipes carrying the biogas or by means of a demister followed by a two-phase separator.

3) Elimination of carbon dioxide

If the water contents must be very low, for example, for injection into the gas network, the presence of a higher quantity of CO₂ is a major drawback for biogas used as fuel or injected into the city gas network, so it must be almost free of CO₂ or must contain more than 96% methane.

The biogas washing techniques mentioned above also make it possible to remove CO₂ from biogas [39]. Given the solubility of CO₂, which is much higher than that of methane, biogas can be bubbled through a solvent bath to trap the CO₂. Water, polyethylene glycol or water with added soda are common solvents. Hayes *et al.* (1990) thus obtained, by washing with water, a biogas containing 93% methane [40], Harasimowicz *et al.* (2007) obtained a biogas containing 94% methane [41], O'Keefe *et al.* (2000) showed that washing the biogas by micro-aeration of the liquid phase did not inhibit methanogenic bacteria, while providing good results of biogas containing 90% methane [42]. The biogas is purified and then used to power a cogeneration engine, and thus produce electricity and heat.

Table 3 gives us information on the taking of samples from 21 to 26 May, depending on the temperature. It is quite illustrative for the interpretation of the observed data on the inlet and outlet of the characteristics of the biogas as a function of the temperature used for this purpose.

Table 3. Samples from May 21 to 26, according to temperature.

Dates	Outside temperature	Observation	
		Reactor crude production	Reactor exit
21/05/2024	32.9	CH ₄ = 61	CH ₄ = 60
		CO ₂ = 27	CO ₂ = 27
		O ₂ = 0.0	O ₂ = 0.0
		H ₂ S = 360 ppm	H ₂ S = 0 ppm
22/05/2024	33.1	CH ₄ = 54	CH ₄ = 59
		CO ₂ = 26	CO ₂ = 26
		O ₂ = 4.1	O ₂ = 0.6
		H ₂ S = 68 ppm	H ₂ S = 0.0 ppm
23/05/2024	33.3	CH ₄ = 55	CH ₄ = 59
		CO ₂ = 18	CO ₂ = 19
		O ₂ = 3.8	O ₂ = 2.7
		H ₂ S = 52 ppm	H ₂ S = 4 ppm
24/05/2024	33.6	CH ₄ = 59	CH ₄ = 61
		CO ₂ = 20	CO ₂ = 27
		O ₂ = 5	O ₂ = 1.7
		H ₂ S = 265 ppm	H ₂ S = 20 ppm

Continued

			CH ₄ = 58	CH ₄ = 61
			CO ₂ = 24	CO ₂ = 28
25/05/2024	33.5		O ₂ = 0.0	O ₂ = 0.0
			H ₂ S = 0.18 ppm	H ₂ S = 0 ppm
			CH ₄ = 59	CH ₄ = 61
26/05/2024	33.5		CO ₂ = 26	CO ₂ = 28
			O ₂ = 0.2	O ₂ = 0.20
			H ₂ S = 290 ppm	H ₂ S = 0 ppm

3.3. Result of the Simulation of Energy Production after Refining Over Two Years of Biogas Production

Based on the data in **Table 3**, **Figure 5**, which is illustrated, can be explained by the fact that the addition of manure in the substrate during the period June-August allowed to increase the quantity of production until the month of September before falling and rising again in the last month with of course another addition of manure.

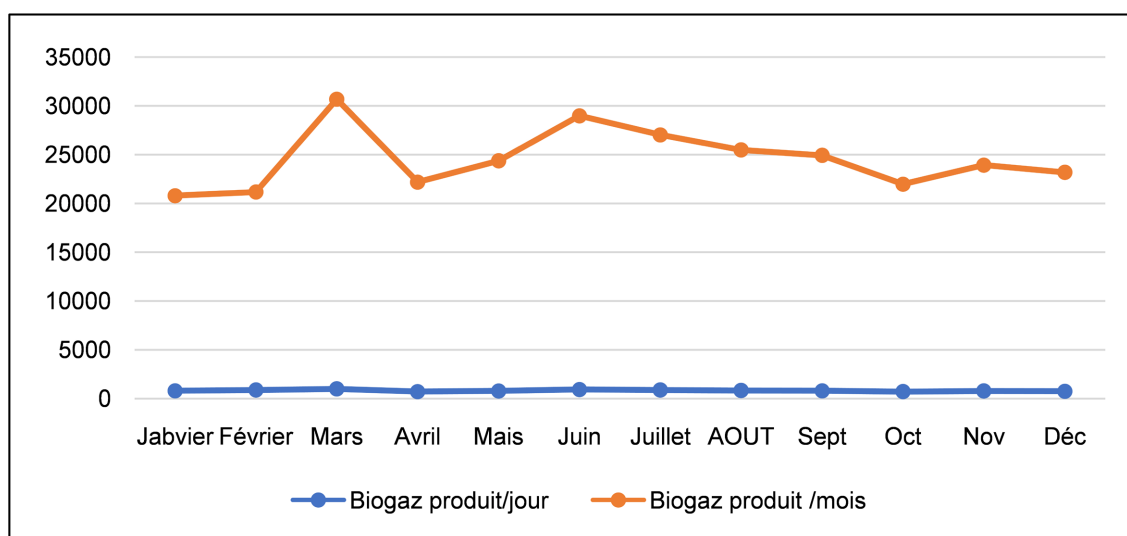


Figure 5. Simulation of biogas production per day and per month for the first year.

The temperature factor can have an explanation for this interval also because from the month of May to July, the weather is hot, and if we did not modify the substrate by the addition of manure, the temperature will impact the quantity of biogas produced and will make it fall even more.

From the data on the production of biogas produced per day and per month for the first year, **Figure 6** can be illustrated, which gives a simulation of the energy production for the first year. The ratio of heat production to energy production can be seen on the graph of the histogram of the first year.

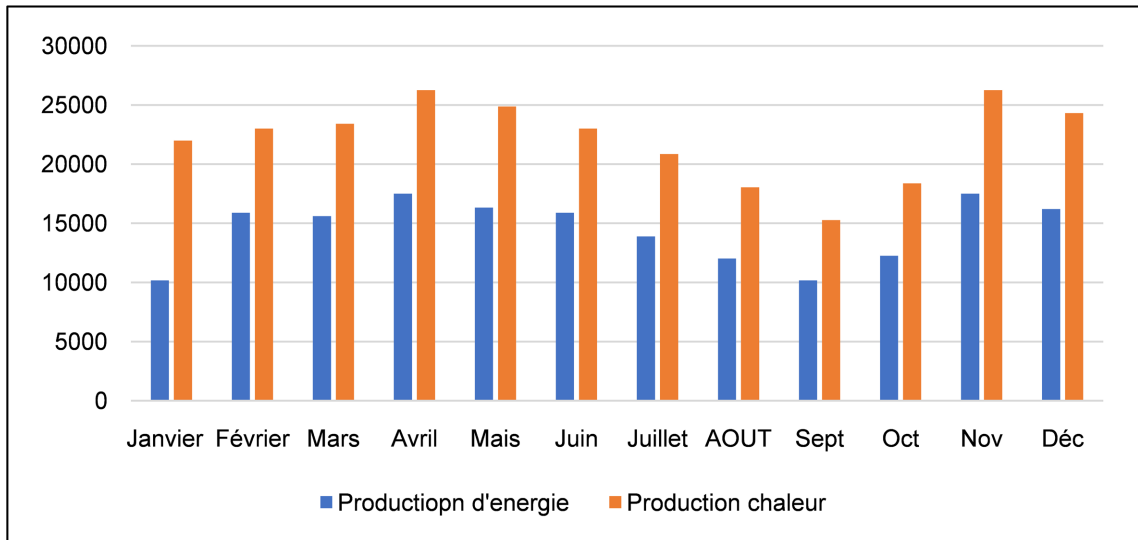


Figure 6. Simulation of energy production for the first year.

Theoretically, it is a little difficult to explain the implication of temperature in these data because the distribution of the ratio differs from one month to another and therefore it remains the only theoretical explanatory factor on the yield of biogas. However, the type of substrate, ratio and mode of introduction does not allow us to confirm or deny whether the quality of the substrate or the composition of the ratio mixture can positively impact the yield in terms of quantity and quality of biogas. What we notice on the simulation results in the second year also

What we notice about the simulation results in the second year in **Figure 7**.

Starting from the data of the second year in the previous (**Figure 7**), the ratio of heat production to energy production can be illustrated in the second year by the data of the operations carried out in the second year, which gives us an overview in **Figure 8**.

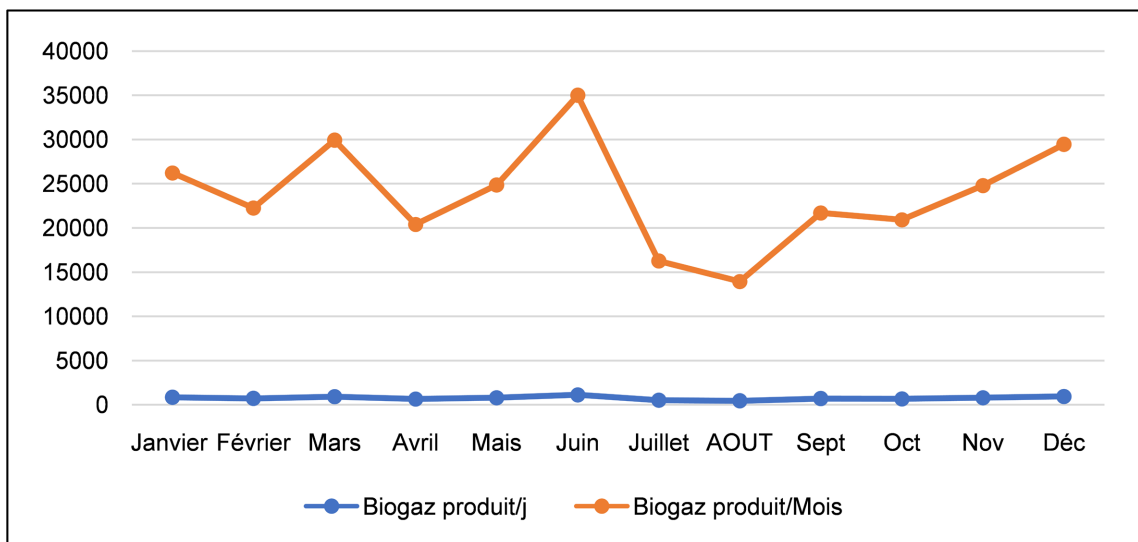


Figure 7. Simulation of biogas production produced per day and per month from the second year.

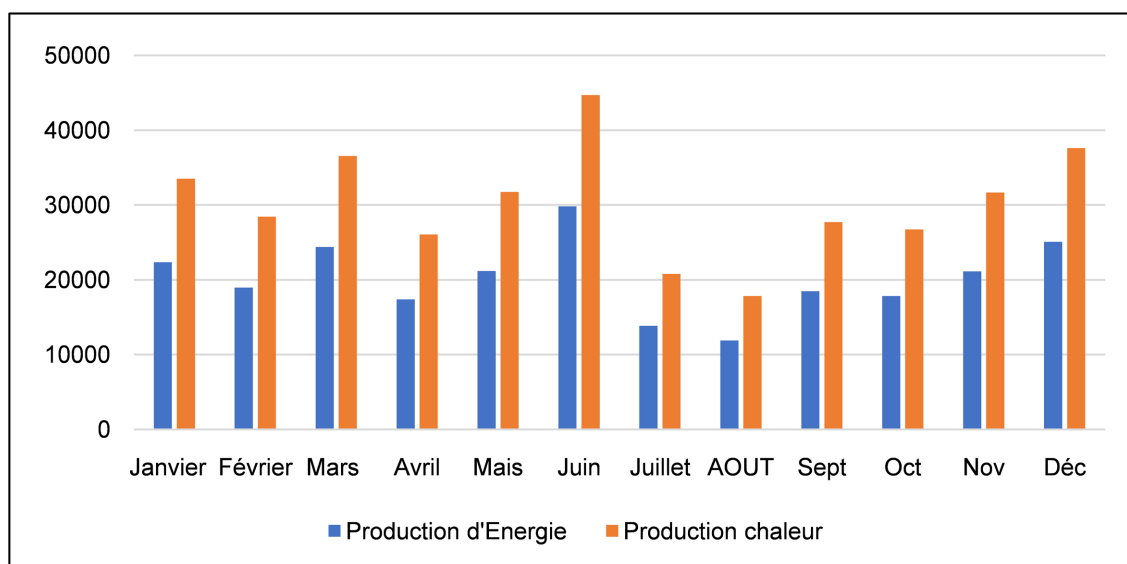


Figure 8. Simulation of energy production for the second year.

It is noted that the inputs of the substrates differ from one month to another and the production of biogas is also not stable with a higher peak in March and slightly in June. That of March can be explained by the fact that the elements having contributed to the start of the methanization process being in an environment free of secondary reaction but also respecting the conditions of implementation of biogas production. Added to this is also the climate, which by the temperature, can negatively or positively influence the reaction mechanism in an anaerobic environment. Generally, from January to April, the weather is a little cool and the heat is due to the sunshine, that is to say, the temperature does not affect the reactions too much. Thus, the production of biogas is better favored, but we constant that after the peak of March, there is a drop in the quantity of biogas until May but proportional to the quantity of the substrate introduced.

4. Conclusions

The performance of anaerobic digesters depends on the characteristics of the treated effluent and the type of digester used, depending on a yield that can be either in quality or quantity. Generally speaking, purification yields can vary from 60% - 98% on raw biogas. The calorific value of a combustible compound represents the energy released by the combustion of the latter. Methane is the only biogas compound that is energetically interesting, and the calorific value of the mixture depends only on the partial pressure of methane. For pure methane, the calorific value is $12.67 \text{ kWh}\cdot\text{m}^{-3}$, and for a biogas containing 70% CH_4 , it will therefore be $8.87 \text{ kWh}\cdot\text{m}^{-3}$, or $32 \text{ MJ}\cdot\text{m}^{-3}$.

Despite everything, the residual quantity of pollution often remains too high for direct discharge into the natural environment and therefore requires aerobic finishing. In our specific case, the raw biogas before its purification and the purified one does not present a wide range of differences. The sentence should be corrected

as follows: The tables shown in the document show different variations in the biogas flow rate during the selected months, although the technology used until then remains unchanged. The variation of the results over each month can be explained by the climatic situation of the country. We have seen previously that the temperature is an important factor in having a good kinetics of transformation of organic pollution in the digesters. The influence of the climate can play a negative or positive role on the biodigester if we do not control the outline or if the positioning of the biodigester does not respect the standards.

Acknowledgments

At the end of this work, we would like to thank the AfricLab Laboratory and Mrs. Fatimé Haroun.

Conflicts of Interest

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

References

- [1] Adannou, H.A., Goni, S., Abderaman, M.B., Khayal, M.Y., Khamis, A.A., Aidara, M., *et al.* (2019) Influence of Climate Temperature on the Valorization of Dung-Wastewater Slaughterhouse Biogas in Two Regions: In Chad and Senegal. *Natural Resources*, **10**, 81-95. <https://doi.org/10.4236/nr.2019.104006>
- [2] Demeyer, A., Jacob, F., Jay, M., Menguy, G. and Perrier, J. (1980) La Conversion bioénergétique du rayonnement solaire et les biotechnologies. Edition Tec & Doc., 213-215.
- [3] Méthanisation (n.d.) Etapes de la digestion anaérobie. <http://www.methanisation.info/etapes.html>
- [4] 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>
- [5] Afilal, M.E., Belkhadir, N., Daoudi, H. and Elasri, O. (2013) Fermentation méthanique des différents substrats organiques, *Journal of Materials and Environmental Science*, **4**, 11-16.
- [6] Douag-Tirichine, N., Benkhalifa, A. and Bousdira, K. (2023) Production de biogaz à partir des déjections bovines en milieu aride: Cas du M'Zab (Algérie). *Journal of Renewable Energies*, **17**, 419-426. <https://doi.org/10.54966/jreen.v17i3.455>
- [7] Observer (2006) 6e Bilan. État des énergies renouvelables en Europe. Rapport Technique, EurObserver.
- [8] Vechiu, I. (2005) Modélisation et analyse de l'intégration des énergies renouvelables dans un réseau autonome. Thèse de Doctorat, Université du Havre.
- [9] Lusk, P.D. (1998) Methane Recovery from Animal Manures. The Current Opportunities Case-Book. Rapport Technique, National Renewable Energy Laboratory.
- [10] Godon J.-J. (2008) Aspects biochimiques et microbiologiques de la méthanisation. In: Moletta, R., Ed., *La Méthanisation*, Editions Tec & Doc., 62-85.
- [11] Moletta, R. and Verstraete, W. (2008) La méthanisation dans la problématique énergétique et environnementale. In: Moletta, R., Ed., *La Méthanisation*, Edition Tec & Doc., 3-8.

- [12] Chanakya, H.N., Reddy, B.V.V. and Modak, J. (2009) Biomethanation of Herbaceous Biomass Residues Using 3-Zone Plug Flow Like Digesters—A Case Study from India. *Renewable Energy*, **34**, 416-420. <https://doi.org/10.1016/j.renene.2008.05.003>
- [13] Jagadish, K.S., Chanakya, H.N., Rajabapaiah, P. and Anand, V. (1998) Plug Flow Digestors for Biogas Generation from Leaf Biomass. *Biomass and Bioenergy*, **14**, 415-423. [https://doi.org/10.1016/s0961-9534\(98\)00003-8](https://doi.org/10.1016/s0961-9534(98)00003-8)
- [14] Bernet, N. and Buffière, P. (2008) Caractérisation de la mise en œuvre de la méthanisation. In: Moletta, R., Ed., *La Méthanisation*, Edition Tec & Doc.
- [15] Mata-Alvarez, J. (2002) Fundamentals of the Anaerobic Digestion Proches. In: Mata-Alvarez, J., Ed., *Biomethanization of the Organic Fraction of Municipal Solid Wastes*, IWA Publishing, 1-20.
- [16] Marchaim, U. (1992) Biogas Processes for Sustainable Development. FAO.
- [17] Yadvika, Santosh, Sreekrishnan, T.R., Kohli, S. and Rana, V. (2004) Enhancement of Biogas Production from Solid Substrates Using Different Techniques—A Review. *Bioresourcetechnology*, **95**, 1-10. <https://doi.org/10.1016/j.biortech.2004.02.010>
- [18] Moletta, R. (2011) La méthanisation. 2ième Edition, Tec & Doc. Lavoisier.
- [19] Schnürer, A. and Jarvis, Å. (2010) Microbiological Handbook for Biogas Plants, Swedish Waste Management, Swedish Gas Centre Report. Branch Ministry of Agriculture and Lands.
- [20] Pavlostathis, S.G. and Giraldo-Gomez, E. (1991) Kinetics of Anaerobic Treatment: A Critical Review. *Critical Reviews in Environmental Control*, **21**, 411-490. <https://doi.org/10.1080/10643389109388424>
- [21] Bollon, J., Le-hyaric, R., Benbelkacem, H. and Buffiere, P. (2011) Development of a Kinetic Model for Anaerobic Dry Digestion Processes: Focus on Acetate Degradation and Moisture Content. *Biochemical Engineering Journal*, **56**, 212-218. <https://doi.org/10.1016/j.bej.2011.06.011>
- [22] Gujer, W. and Zehnder, A.J.B. (1983) Conversion Processes in Anaerobic Digestion. *Water Science and Technology*, **15**, 127-167. <https://doi.org/10.2166/wst.1983.0164>
- [23] Nabila, L. (2016) Dépollution des déchets riches en matière organique (Boues de station d'épuration et déchets d'abattoir) par digestion anaérobie: Valorisation énergétique et production du méthane. Thèses de Doctorat, Université Badji Mokhtar-Annaba.
- [24] Bernet, N. and Buffière, P. (2011) Caractérisation de la mise en œuvre de la méthanisation. In Moletta, R., Ed., *La Méthanisation*, 2nd Edition, Edition Tec & Doc., 87-113.
- [25] Camacho, P. and Prévot, C. (2011) Méthanisation des boues. In: Moletta, R., Ed., *La Méthanisation*, 2nd Edition, Edition Tec & Doc., 87-113.
- [26] Athanasoulia, E., Melidis, P. and Aivasidis, A. (2012) Optimization of Biogas Production from Waste Activated Sludge through Serial Digestion. *Renewable Energy*, **47**, 147-151. <https://doi.org/10.1016/j.renene.2012.04.038>
- [27] Lagrange, B. (1989) Biométhane, Principes-Techniques-Utilisations. Ed. Edisud.
- [28] Théophile, E.M. and Karim, K.S. (n.d.) Etude, conception et réalisation d'un biodigester domestique pour la production du biogaz: Application aux lisiers de porc. Mémoire en Ligne.
- [29] Adannou, H.A. (2019) Production industrielle du biogaz et valorisation énergétique: Etude du digesteur à bache utilisant les déchets d'abattoirs. Thèse de Doctorat, Université Cheikh Anta Diop de Dakar.
- [30] Adannou, H.A., *et al.* (2019) Experimental Contribution to the Phenomena of Methanisation by Co-Digestion of Organic Waste from the Residence of the Cheikh Anta

- Diop University in Dakar. *Applied Ecology and Environmental Sciences*, **7**, 56-65.
- [31] Li, K. and Teo, W.K. (1993) Use of an Internally Staged Permeator in the Enrichment of Methane from Biogas. *Journal of Membrane Science*, **78**, 181-190. [https://doi.org/10.1016/0376-7388\(93\)85259-y](https://doi.org/10.1016/0376-7388(93)85259-y)
- [32] Gadre, R.V. (1989) Removal of Hydrogen Sulfide from Biogas by Chemoautotrophic Fixed-Film Bioreactor. *Biotechnology and Bioengineering*, **34**, 410-414. <https://doi.org/10.1002/bit.260340317>
- [33] Travieso, L., Sánchez, E.P., Benitez, F. and Conde, J.L. (1993) *Arthospira* sp. Intensive Cultures for Food and Biogas Purification. *Biotechnology Letters*, **15**, 1091-1094. <https://doi.org/10.1007/bf00129944>
- [34] Syed, M., Soreanu, G., Falletta, P. and Bäcland, M. (2006) Removal of Hydrogen Sulfide from Gas Streams Using Biological Processes—A Review. *Canadian Biosystems Engineering*, **48**, 1-14.
- [35] Adannou, H.A. (2024) Study of a Theoretical Approach to Bioprocess Modeling for the Performance of an Anaerobic Digester. *GSC Advanced Research and Reviews*, **21**, 25-37. <https://doi.org/10.30574/gscarr.2024.21.2.0407>
- [36] Wheeler, P., Jaatinen, T., Lindberg, A., Holm-Nielsen, J.B., Wellinger, A. and Petti-grew, A. (2000) Biogas Upgrading and Utilisation: Energy from Biological Conversion of Organic Waste. IEA-Bioenergy.
- [37] Horikawa, M.S., Rossi, F., Gimenes, M.L., Costa, C.M.M. and da Silva, M.G.C. (2004) Chemical Absorption of H₂S for Biogas Purification. *Brazilian Journal of Chemical Engineering*, **21**, 415-422. <https://doi.org/10.1590/s0104-66322004000300006>
- [38] Kapdi, S.S., Vijay, V.K., Rajesh, S.K. and Prasad, R. (2005) Biogas Scrubbing, Compression and Storage: Perspective and Prospectus in Indian Context. *Renewable Energy*, **30**, 1195-1202. <https://doi.org/10.1016/j.renene.2004.09.012>
- [39] Coombs, J. and Meynell, P.J. (1982) Cleaning Biogas. *The Digest (Newsletter of the BABA)*, **10**, 5-9.
- [40] Hayes, T.D., Isaacson, H.R., Pfeffer, J.T. and Liu, Y.M. (1990) *In Situ* Methane Enrichment in Anaerobic Digestion. *Biotechnology and Bioengineering*, **35**, 73-86. <https://doi.org/10.1002/bit.260350111>
- [41] Harasimowicz, M., Orluk, P., Zakrzewska-Trznadel, G. and Chmielewski, A.G. (2007) Application of Polyimide Membranes for Biogas Purification and Enrichment. *Journal of Hazardous Materials*, **144**, 698-702. <https://doi.org/10.1016/j.jhazmat.2007.01.098>
- [42] O'Keefe, D.M., Brigmon, R.L. and Chynoweth, D.P. (2000) Influence of Methane Enrichment by Aeration of Recirculated Supernatant on Microbial Activities during Anaerobic Digestion. *Bioresource Technology*, **71**, 217-224. [https://doi.org/10.1016/s0960-8524\(99\)90073-1](https://doi.org/10.1016/s0960-8524(99)90073-1)