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Study of the methanogenic potential of urban waste from the city of N'Djamena for recovery into biogas

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Abstract

The different types of urban waste as well as household waste are generally disposed of in open landfills affecting environmental sustainability. These wastes, by the release of contaminants such as leachates and greenhouse gases, increase the pollution potential of the sites. We recovered a quantity to carry out our experiments. The recovery of waste into biogas inevitably takes place in hermetically sealed enclosures called biodigesters. In this work we highlighted several types of waste at room temperature in a 0.75l can equipped with an empty inflatable balloon used for the recovery of biogas, which constituted our biodigester. Then a second experiment was carried out on the mesophilic temperature and the results were compared. The aim is to see the waste with the best biogas potential in terms of quality and quantity of production. The experiment consisted of working at an ambient temperature around 35°C±2 °C and up to 45 °C (mesophilic temperature). For this experiment we found that some bio-digesters started producing after two hours of time, the inflatable balloon increased in volume every hour up to 24 hours before and remained constant. We used the resources in terms of substrate and equipment of the Afric-Lab laboratory and that of the Physics-Chemistry department of the Higher Normal School of N'Djamena.

Keywords: Urban waste; Environmental sustainability; Mesophilic temperature; Biodigester; Afric-Lab Laboratory

1. Introduction

With ever-increasing and more diversified consumption worldwide, waste production continues to increase in quantity and quality, thus generating enormous risks to the environment and, consequently, to the health of the population [1-3]. In the current global context, the management and recovery of organic waste, particularly biomass, constitutes a considerable economic, environmental and energy challenge. The use of the latter is both a necessity and an economic opportunity opening new avenues for sustainable development. [4-5].

Resulting from the methanization or anaerobic digestion of fermentable waste in hermetically sealed enclosures called digesters, [6] purified biogas is used as green energy and presents itself as an alternative energy source to replace fossil fuels. [7-10] It is an opportunity for diversification of energy resources and sustainable management of the environment in rural areas. Anaerobic digestion represents one of the major players in sustainable development and the circular economy in the concept of "waste to energy". Given the great diversity of organic waste, its development requires the optimization of co-digestion. Hence the need to develop simple tools to characterize substrates and to predict the performance of digesters in order to optimize their operation.[11]. In our case, to date in Chad, kitchens run on coal, cow and camel dung, domes, etc. As a reminder, for environmental protection reasons, firewood was banned in Chad a

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few years ago. Butane gas remains the only source of cooking energy in addition to the other elements mentioned above. [12]. We therefore believe that the research in this article could contribute to finding an alternative to produce and use biogas for several purposes

2. Material and methods

2.1. Materials used

In our experiments we used the materials mentioned below for the experimental realization of biogas production:

- Chicken waste;
- Corn waste (bran);
- Millet waste (bran);
- Millet waste (bran) (bérébéré)
- Fish waste;
- Empty 750ml bottles;
- Sticky balloons;
- Gloves;
- A butane gas canister;
- A pot;
- An electronic thermometer;
- A cup (measuring instrument)
- A bucket (instrument for making the mixture).
- Ten 750mL plastic bottles
- Ten inflatable balloons
- A knife
- An electronic thermometer
- A pair of gloves,
- A shovel

2.2. Work methodology

To obtain a significant production of biogas, close contact between the bacteria and the substrate is required, which is generally obtained with effective mixing in the digestion tank. Good agitation prevents the production of crusts and the decantation of dense particles, which breaks the floating layer and thus facilitates the escape of biogas [13]. The methodology adopted in this work is that of [14-15]. We collected various wastes to allow us to carry out our experiment on the production of biogas. For this reason, wastes such as rice bran were collected with the housewives once the various cereals mentioned above had been pounded.

For the chicken waste, we collected them directly in a chicken coop.

Dry waste to bring to the laboratory for our experiment.

Finally, the fish waste is taken with the women traders at the Dembé market (N'Djamena), all the parts they throw in the trash. Table 1 presents the different types and mixtures of substrate used for our experiments.

Table 1 Summary of the different digesters for the experiment

D1: corn waste (DMa)	D5: chicken/millet waste (Dpou v DMi)
D2: fish waste (DPoi)	D6: chicken/millet waste (Dpou v DM)
D3: chicken/fish waste (DPou v DPoi)	D7: chicken/corn waste (Dpou v DMa)
D4: chicken/rice waste (Dpou v DRi)	D8: whole mixture waste (DTM)

2.2.1. Preparation of waste

First of all, we would like to carry out eight different types of experiment, therefore we have eight digesters.

Of the eight digesters, two digesters must each contain a waste without mixture and of different nature.

The five digesters must each contain two types of waste, one of which would be chicken waste.

One of the digesters must contain the mixture of all the waste. Thus, we placed the waste in the following manner:

Corn waste (bran) (alone);

- Fish waste (alone);
- Chicken waste + fish;
- Chicken waste + rice;
- Chicken waste + millet (small millet);
- Chicken waste + millet (bérébéré);
- Chicken waste + corn;
- Chicken waste + fish + corn + millet + millet + rice.

In the second experiment on the effect of temperature, the waste used was composed of:

- Dry cow dung (BCD)
- Fresh cow dung (FCD)

We took a cup as a measuring instrument which is used for the same quantity of waste before mixing them until obtaining a homogeneous body.

NB: for waste without mixing, the quantity is equal to the quantity of the two mixed wastes.

We present you the image of the different wastes collected before mixing.

Figure 1 Different wastes collected before mixing

2.2.2. Experimental condition

For a good fermentation, we reduce the large particles into powder in order to obtain a homogeneous body. Once we obtain a homogeneous mixture, we introduce the mixture into the digester (bottle) half full.

We heat water to 45 °C (measured with an electronic thermometer); then; we add this water to the mixture while shaking until we obtain a homogeneous solution filling the bottle.

Finally, the bottle is tightly closed with great care not to damage it, the inflating balloon inserted into the cap so as not to let air in

3. Results and discussion

The methanogenic potential of a mixture of substrates can be different from the sum of the methanogenic potentials of the constituent substrates of the mixture [16]. This is what we noticed during our experiments. In some cases, the methanogenic potential of a mixture of substrates is greater than the sum of the methanogenic potentials of the constituent substrates, which reflects a synergy between the substrates of the mixture while, in other cases, an antagonism is observed. The mixing conditions of the substrates can significantly impact the performance of the digester for the production of biogas. Several parameters make it possible to control the methanization processes [17] [18]. KALIA et al. (1992) have proven that the digestion efficiency could be increased or slowed down depending on the nature of the waste [19] HAROUN et al (2019)A have demonstrated that the nature of the different substrates as well as the operating conditions could influence the increase or decrease of biogas. The biogas obtained is flammable from the seventh day and according to Laloe, 2003 [20] and Dartigalongue et al, 2004 [21] it is composed of at least 45% methane.

The total volume of biogas produced is 280.31 Nml. The specific production [22], is equal to 17.52 Nml/g DM. The yield of the biogas obtained is 30.30 Nml/mg of degraded COD. The same orders of magnitude were reported by Deng et al, 2006 [23]

3.1. Presentation of the results of the Experiment

Figure 2 Implementation of the digesters at time T = Start of experiment without agitation

It is 9:10 am when we started with our experiment, the temperature of the room was at 31 °C. At the end of our assembly, we had taken the temperature measurement again, it was 35 °C at 1:00 pm.

3.1.1. Results of the different experiments at room temperature

Measurement and analysis of fermentation parameters

We will present the result of twenty-seven (27) days based on the increase in the estimated volume in each balloon and the temperature recorded each day in a table followed by the curve that will show the appearance of the speed in the production of biogas in each digester.

- On the first day, less than an hour after setting up our methanization, we noted the formation of biogas in the digester containing the mixture of fish + chicken waste (white balloon).
- On 09/23/2023, we entered the room at 08:34.

We took the temperature of the room which was 29 °C.

We noted the swelling of all the digester balloons.

However, a big difference is observed on the balloon containing the chicken waste + fish which is swollen more than the others, followed by the three (3); namely: the digest er containing the mixture of all the waste, the digester containing the chicken waste + rice and the digester containing the chicken waste + corn.

Then, the balloons containing the mixture of corn waste alone, the chicken waste + millet and the chicken waste + millet have an average swelling.

Finally, the digester containing the fish waste alone, has a balloon whose swelling is weak. We present to you the image of our observation after 24 hours of the formation of biogas.

Figure 3 Implementation of the digesters at time T= During the experiment with agitation

We took the time to shake each digester in order to obtain a homogeneous solution to facilitate the formation of biogas.

These experiments are carried out every day for a month.

3.1.2. Experimental result with a single substrate at room temperature with stirring once a day

3.2. For the experiment, we were able to retain the measurement information represented in table 2 below

Table 2 Collection of measurements carried out from a single substrate at room temperature with stirring once a day

Date	VD1(en ml)	VD2(en ml)
22/09/2023	0	0
23/09/2023	20	20
24/09/2023	60	40
25/09/2023	40	20
26/09/2023	40	30
27/09/2023	60	40
28/09/2023	60	35
29/09/2023	80	30
30/09/2023	90	20
01/10/2023	100	20
02/10/2023	100	20
03/10/2023	90	15
04/10/2023	90	15
05/10/2023	70	10
06/10/2023	60	10
07/10/2023	60	5
08/10/2023	50	5
09/10/2023	50	5
10/10/2023	50	5
11/10/2023	50	
12/10/2023	30	5

13/10/2023	30	0
14/10/2023	30	0
15/10/2023	30	0
16/10/2023	20	0
17/10/2023	20	0
18/10/2023	20	0
19/10/2023	20	0
20/10/2023	20	0
21/10/2023	20	0
22/10/2023	20	0

In this table; we have grouped all the experiments carried out on a single substrate; we note that for most of the analyses the productions as a function of time, temperature, and agitation are in favor of VD1 than that represented by VD2

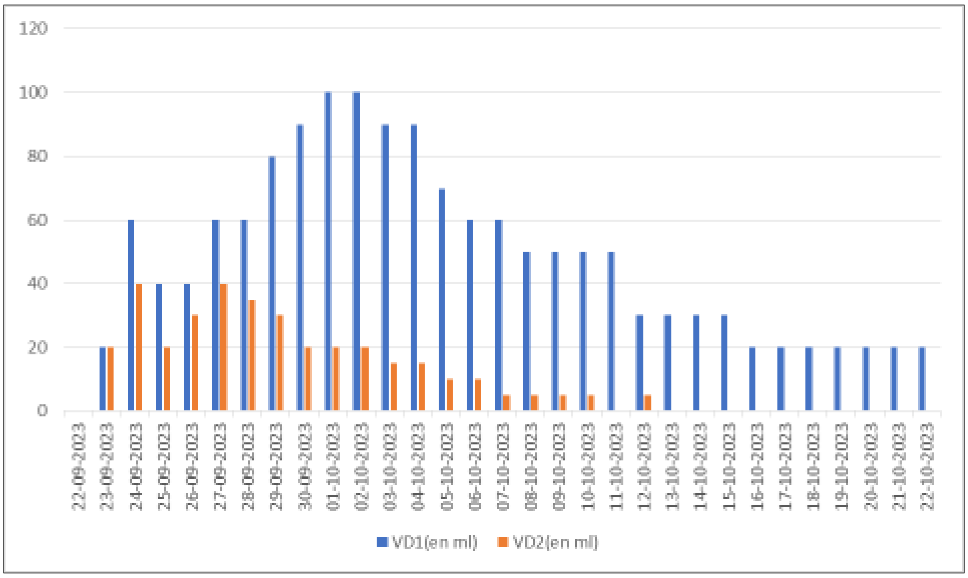

Figure 4 Histogram of measurements made from a single substrate at room temperature with one stirring per day

With a room temperature measured at 08:30' which was 28'4 °C

We made the observations as follows:

- The digester containing chicken waste + corn, has a slight swelling of the balloon
- The digester containing chicken waste + millet, also has its balloon which has increased very slightly
- The digester containing chicken waste + millet, has an increase in biogas in its balloon;
- The digester containing fish waste (alone), has not always produced in its balloon the quantity of biogas,
- The digester containing corn waste (alone), has the volume of the balloon remained standard
- The digester containing chicken waste + fish, continues to lose the quantity of biogas contained in its balloon;
- The digester containing the mixture of all waste (chicken + fish + rice + corn + millet + millet), has a clear increase in the quantity of biogas in its balloon

3.2.1. Experimental result on Co-digestion at room temperature with one stirring per day

The following table 3 presents the results of a series of experiments carried out

Table 3 Result of the experiment on Co-digestion at room temperature with one stirring per day

Date	VD3(en ml)	VD4(en ml)	VD5(enml)	VD6(enml)	VD7(en ml)	VD8(en ml)
22/09/2023	20	0	0	0	0	0
23/09/2023	60	40	20	20	20	40
24/09/2023	100	100	40	60	40	80
25/09/2023	140	100	40	60	40	80
26/09/2023	120	100	20	40	20	70
27/09/2023	120	160	60	50	40	60
28/09/2023	100	140	90	90	50	80
28/09/2023	150	170	140	120	70	100
29/09/2023	180	210	180	180	120	130
30/09/2023	200	230	190	180	120	160
01/10/2023	200	230	210	200	170	190
02/10/2023	210	250	250	230	200	220
03/10/2023	230	250	240	230	220	240
04/10/2023	230	240	250	240	250	240
05/10/2023	250	240	250	230	250	250
06/10/2023	250	250	220	250	230	250
07/10/2023	220	250	220	240	230	230
08/10/2023	210	240	200	230	220	210
09/10/2023	200	220	200	210	200	210
10/10/2023	190	200	190	180	170	190
11/10/2023	190	190	170	160	170	180
12/10/2023	160	170	150	140	160	160
13/10/2023	160	150	150	120	140	150
14/10/2023	130	130	140	120	140	150
15/10/2023	130	130	140	120	140	130
16/10/2023	130	130	110	120	140	130
17/10/2023	130	130	110	120	140	130
18/10/2023	130	130	110	120	140	130
19/10/2023	130	130	110	120	140	130
20/10/2023	130	130	110	120	140	130

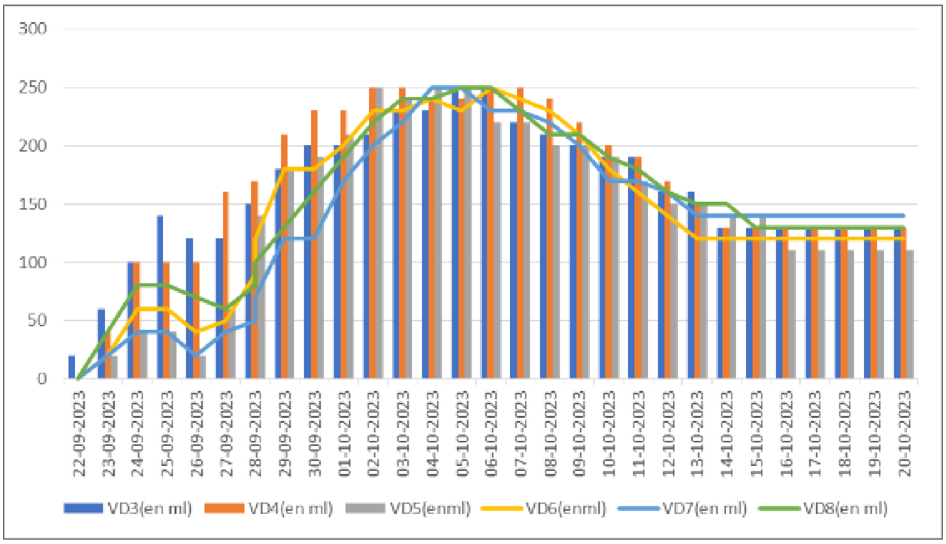

Figure 5 Histogram of measurements taken from several substrates at room temperature with two stirrings per day

3.3. Result of the Impact of Temperature on Biogas Production

The room temperature measurement is 30 °C at 08:15.

We recorded the different ambient temperatures in the digesters as follows

- The temperature in the digester containing BVF is 30.3 °C
- The temperature in the digester containing BVS is 30 °C

For those placed in the water bath at 45 °C respecting the mesophilic temperature, we measured the temperatures as follows:

- The temperature in the digester containing BVF is 42.1°C
- The temperature in the digester containing BVS is 45°C

The following figure 5 gives us an overview of the variation in the production rate during a day and during a week.

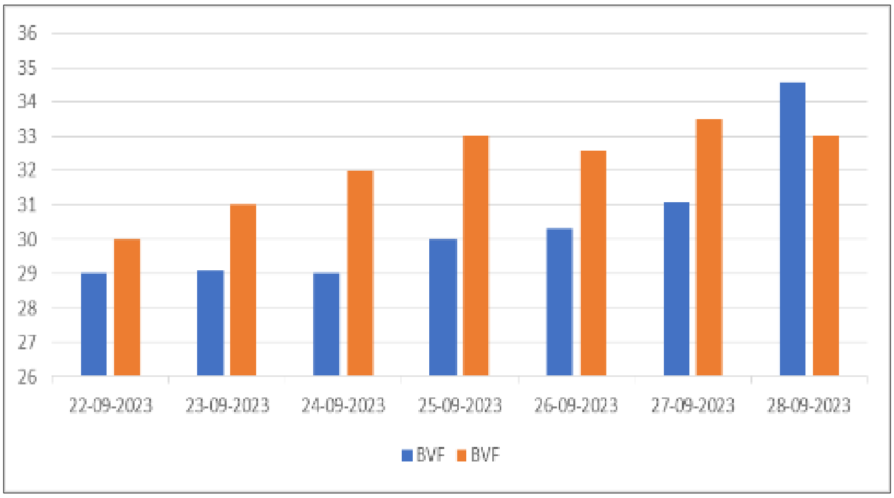

Figure 6 Influence of temperature on biogas production for fresh cow dung at room temperature in one week

We note in this figure that the difference in production is always towards the hottest hours in the case of fresh cow dung. The substrate is much more productive when the temperature of the day increases. We also noticed that over time there was a high flow in the first hours of the day; this is the last day of the experiment and this is also explained.

This time is a function of the temperature, the dry matter rate, the nature and composition of the substrate: the higher the temperature, the faster the digestion, the richer the substrate is in water and fine particles, the faster the digestion.

It depends on the nature, viscosity, and composition of the substrate, [24-25].

Compared to the second experiment on the Mesophilic temperature, we note in Figure 6 below that there is always an increase in production during the day and with the rise in the Mesophilic temperature.

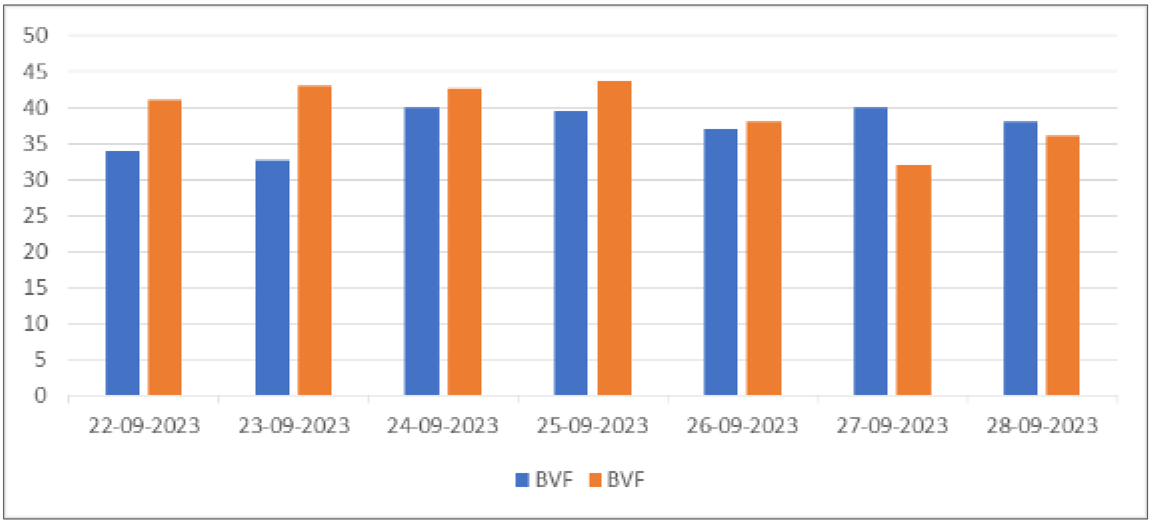

Figure 7 Influence of temperature on biogas production for fresh cow dung at mesophilic temperature in one week

Another series of experiments was done on dry cow dung: the following figures 7 and 8 give us an overview of the temperature variation under room temperature (Figure 7) and mesophilic temperature (Figure 8) conditions.

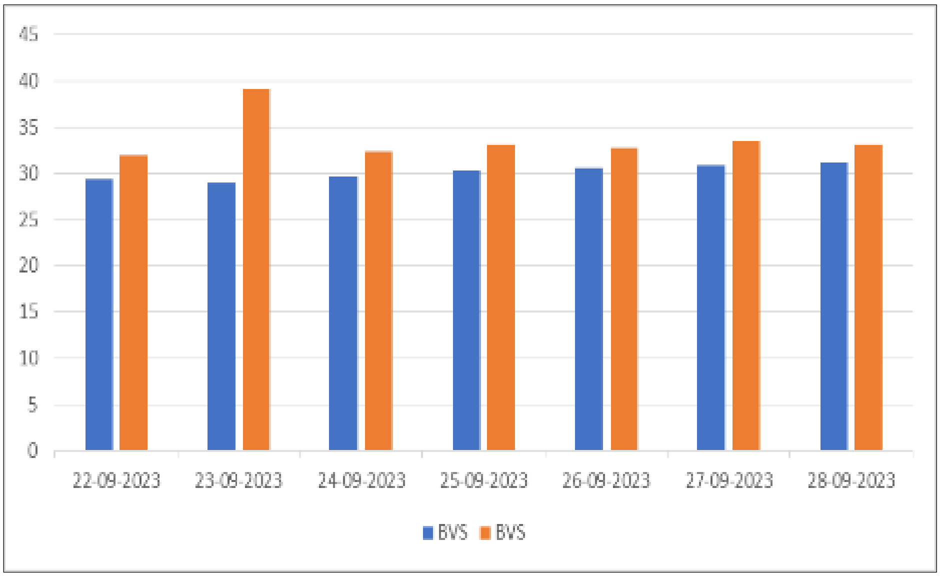

Figure 8 Influence of temperature on biogas production for dry cow dung at room temperature in one week

For this figure 7 we notice that the dry cow dung is influenced by the rise in temperature during the day. The ambient temperature has a minimum of 28°C to 39°C during the day.

As for figure 8 the observation is made in such a way that we note an average in terms of mesophilic temperature on the production of biogas.

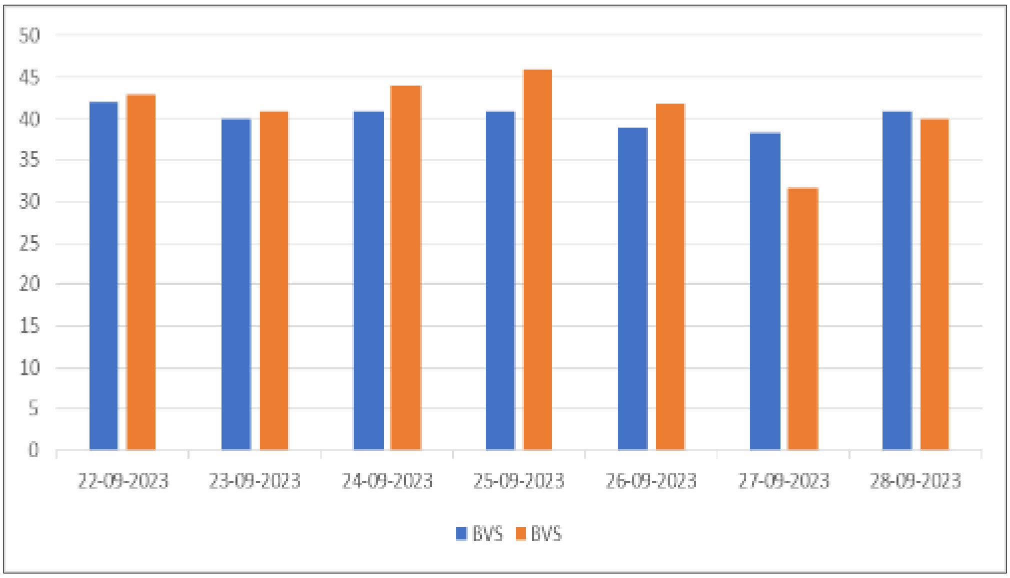

Figure 9 Influence of temperature on biogas production for dry cow dung at mesophilic temperature in one week

In this figure 8, dry cow dung has a more or less higher production at the end of the day and at the beginning of the experiment. We also note that at the end of the week, the production of biogas during the day and depending on the temperature is almost the same on the different temperature thresholds between 40 and 45°C.

4. Discussions

The temperature of AD depends on the tolerance of the microorganisms and is classified as psychrophilic, mesophilic, thermophilic or extrophic [25] established at temperature ranges of 4–25 °C, 30–40 °C, 50–60 °C and >65 °C, respectively [26]. Although anaerobic digestion can be carried out at temperatures below 20 °C [27], below 10 °C, degradation is three times slower than the normal mesophilic process, with methanogenesis becoming the rate-limiting step [28–29]. With higher temperatures, such as those between mesophilic and thermophilic regimes, anaerobic digestion tends to have a perfect environment for biological degradation, resulting in high hydrolysis rates and, consequently, high biogas yields. The amount of methane produced in thermophilic AD is almost the same as that in mesophilic AD, but higher temperatures improve the production rate [30] and reduce the requirement for high operational THS and, consequently, reduce the reactor size [31]. However, the thermophilic digestion system can be energy intensive, unstable, and susceptible to inhibition [33], which, in addition to the robustness of the operation, is the reason why mesophilic processes are currently the most preferred techniques implemented at industrial scale after JC [32]. For a given type of operating temperature, the fluctuation of a few degrees of temperature can have a severe impact on the methane yield, because microorganisms adapt to a certain temperature and the corresponding readaptation to a different temperature requires an alternate microbial structure. It is noteworthy that a variation of the mesophilic temperature of ±4 °C and the thermophilic temperature of ±1 °C resulted in a strong decrease in biogas yield [33-34].

Within physiomicrobial activities, some AD treatment phases are more influenced by temperature than others. For example, the temperature requirements to optimize the growth of methanogenic bacteria, especially mesophilic methanogenic species, may differ from the temperature requirements to optimize hydrolysis or acidification [33-39].

5. Conclusion

During our experiments, we identified and examined the importance of the selection of operational parameters in existing technologies and their impact on biogas yield according to and in accordance with the consulted state of the art literature. We analyzed each of the wastes used in this work under ambient temperature and also under mesophilic temperature. The experimental determination of the Methanogenic potential as a function of temperature parameters led to understand that in the field of raw material use (substrate, inoculum, codigestion and pretreatment), process state (pH, temperature, pressure and reactor design), reactor control and inhibition (ammonia and AGV) at laboratory scale, a non-exhaustive answer exists. In addition, particular emphasis is placed on the comparison of temperature parameters that have been or could be implemented in current or future biogas plants. From the different experiments, we note that, when the temperature of the water bath is not at 45 ° C, all the digester balloons decrease in volume. When the water bath is subjected to a mesophilic temperature between 40-45 ° C, the digester balloons swell more than the other balloons outside the water bath. We note that the digester balloon containing the BVS is sucked up by the digestate and this can be explained by the presence of the inhibitory agents which suck up all the biogas produced in this digester.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

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