IMPROVEMENT OF THE METHANE YIELD FROM THE SLUDGE BY CO-DIGESTION WITH DROMEDARY DUNG IN THE CITY OF ADRAR IN ALGERIA

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The sludge in Adrar, a city located in southwestern Algeria, was co-digested with dromedary dung from the same region. For this, five batch-type digesters with a reaction volume of 1 L and different proportions of substrate were used. The proportions of sludge to dromedary manure substrates were: 0/100, 25/75, 50/50, 75/25 and 100/0. The substrate concentration in the digesters was fixed at 16 g / L of organic matter, with an inoculum to substrate ratio equal to 2/1. Digestion has gone through the mesophilic phase (37 ± 2 °C), with a unified hydraulic retention time of 30 days for all digesters. The volumes of biogas and methane were measured every day during the total period of the experiments, using the biochemical methane potential (BMP) test, pH, and volatile fatty acids (VFA) assay. In addition, the full alkalimetric titer (FAT) was recorded every week, and the organic matter content and the chemical oxygen demand (COD) were registered before and after each experiment. The results obtained showed that for the proportions of 25% of dromedary manure and 75% of sludge allowed having a good anaerobic digestion, which explains the good chemical oxygen demand obtained (32000 - 11666 mg / l). This resulted in the production of large amounts of biogas (1439 ml) and methane (909 ml), with a significant consumption of substrate (45.93%) in comparison with the other proportions used.

Keywords: Sludge, Dromedary dung, Co-digestion, Methanogenic potential, City of Adrar

1. Introduction

Sludge is the most important end product of wastewater treatment plants in developed and developing countries. The amount of sludge is constantly augmenting; it increases with the volume of treated wastewater. Like the other types of waste, the elimination, management and recovery of sludge represents a major challenge worldwide. There are many methods for the valorization of sludge from wastewater treatment. It is possible to cite, among others, the anaerobic digestion which is a biological process in which some specific micro-organisms biodegrade the organic matter (substrate). Indeed, in the absence of free molecular oxygen (O_2) [1], the organic matter is mainly transformed into biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2) with new bacterial

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cells [2]. It is worth noting that the main benefits of the anaerobic digestion are to capture the energy within CH_4 and also to stabilize and destroy the biosolids [3]. Biogas can be produced from many organic sources, such as wastewater and agri-food sludge, animal manure, and even the organic fraction of municipal solid waste [4]. It is worth recalling that there are several techniques, such as pretreatment, that can be utilized in improving the anaerobic digestion, and consequently producing high volumes of biogas with a good methane yield. This can be done either thermally, mechanically, chemically, by ultrasound, or also by bacterial and enzymatic hydrolysis [5].

Co-digestion is one of the most widely used procedures to enhance the anaerobic degradation of waste with different characteristics. In addition, it is possible to carry out a simultaneous biodegradation of different wastes in a reactor in order to establish a positive synergy in an anaerobic digestion medium [6]. The co-digestion process consists of balancing the carbon / nitrogen (C/N) ratio within the mixture of co-substrates, as well as the macro and micronutrients, pH, inhibitors, toxic compounds and dry matter [7].

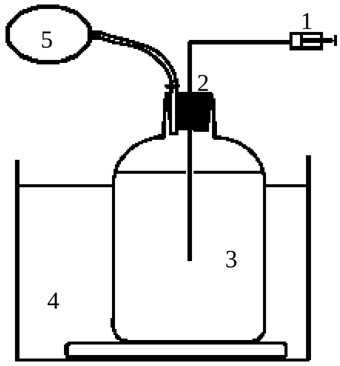
Co-digestion of sludge with municipal solid waste has exhibited a great potential in reducing the environmental impacts and increasing the economic and energetic values of substances through the production of biomethane, electricity and fertilizers. On the other hand, co-digestion of sludge with food waste has shown an optimal transfer of mass within sludge at a rate of 50% of food waste [8]. Furthermore, it has been reported that the co-digestion of sludge and bio-waste may help to reduce significantly the consumption of natural resources and protect the ozone layer; it can, in parallel, ensure better environmental management of bio-waste [9].

The present work aims at using the co-digestion process for the purpose of improving the methane yield from the sludge, from the wastewater treatment plant in the city of Adrar (southeastern Algeria), mixed with dromedary manure which up to now has been used only as an agricultural fertilizer in the Wilaya of Adrar. This study focuses on the energy recovery of two substrates, i.e. sludge and dromedary dung, in order to use them as an amendment for agricultural land, knowing that dromedary manure is a Saharan cellulosic waste that is rich in organic matter and has not been valorized in this region so far.

2. Material and methods

- Experimental setup

The experimental device used is a batch bioreactor which mainly consists of a glass bottle with a capacity of one liter. In addition, two holes are drilled on its cap; the first one is used to take samples using a syringe and the second one allows the biogas produced to escape. It is useful to remember that the bioreactor is hermetically sealed to ensure good anaerobiosis. In addition, the temperature of fermentation is controlled using a water bath at a temperature of 37± 2°C, as indicated in Fig. 1. Then, the produced biogas is transferred by balloon to measurement system and the CO2 elimination.



(1) Sampling syringe; (2) Cap; (3) Glass bottle; (4) Water bath; (5) Storage tank for biogas recovery.
Fig. 1. Laboratory digester Scheme

- The substrates

The substrates studied are fresh sludge from the wastewater treatment plant in the city of Adrar and dromedary manure from the same region. This manure is crushed to facilitate digestion. Characteristic parameters of substrates are summarized in Table 1.

- The inoculum

The inoculum used comes from a digester in operation for more than a month; it contains cow dung from one of the farms near the town of Adrar. This inoculum has the characteristics mentioned in table 1.

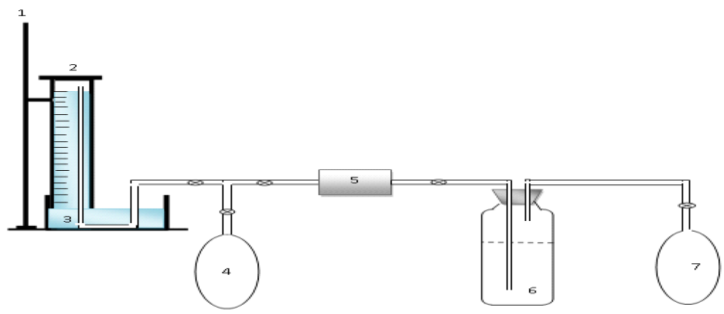
Table 1

Characteristics of the substrates and inoculum before the beginning of the experiment

Parameter	Sludge	Dromedary dung	Inoculum
pH	7.73	8.23	5.81
Dry matter content (%)	48	94.68	21.75
Volatile solid content (VS) (%)	42.83	75.74	94.01
Total chemical oxygen demand (CODT)(g/l)	58.66	21.33	21.74
Soluble chemical oxygen demand (CODS)(g/l)	29.33	53.33	15.23

- Analyses and measurements

The volumes of biogas and methane were recorded on a day-to-day basis using the liquid displacement method, with a saturated solution (NaCl: 10g / l, pH = 2) in order to minimize the dissolution of carbon dioxide (CO_2). In addition, the removal of CO_2 was carried out using a solution of NaOH (3M / l). The biochemical methane potential (BMP) test [10] is presented in Fig. 2.



(1) Stand; (2) Inverted graduated cylinder; (3) Saturated solution (NaCl: 10g / l, pH = 2); (4) Unfiltered biogas; (5) Vacuum pump; (6) CO2 filtration (NaOH solution (3M / l)); (7) Filtered biogas.

Fig. 2. Schematic diagram of the system used for measuring the volumes of biogas and CH_4 produced (Biochemical Methane Potential test).

To calculate the volume of biogas and methane, we used the bio-methane potential (BMP) test, as shown in Fig. 2; The volume of biogas produced (4) was measured by the method of liquid displaced in the Inverted graduated cylinder (2) with a saturated solution (NaCl 10 g/L pH = 2) (3) in order to minimize the dissolution of CO_2, the quantified biogas is pumped (5) into a solution of NaOH (3M / L) (6) to remove the CO2, finally we obtained a pure methane (7) which is quantified by the same previusly cited method.
The pH was measured using a HANNA HI8314 pH meter. The volatile fatty acids (VFAs) and the complete alkalimetric titer (CAT) were recorded each week applying the standard APHA method [11]. In addition, the dry matter content, the organic matter content, the total chemical oxygen demand (CODt) and soluble chemical oxygen demand (CODs) were determined before and after each experiment, using the same method. Also, the analyses of CODs were carried out after centrifugation at 0.45 µm and filtration of the supernatant.

- *Procedures*

All five batch digesters contained the substrates and the inoculum, with a substrate to inoculum ratio equal to 1/2 [12]. The proportions of sludge and manure substrates are given in Table 2.

Table 2.

Proportions of substrates in all five digesters.

Digester	Substrate content %	
	Dromedary manure	Sludge
DI 1	100	0
DI 2	75	25
DI 3	50	50

DI 4	25	75
DI 5	0	100

Three tests were carried out in each digester and the average of the three results was utilized. In addition, operating parameters such as pH, VFA and CAT, as well as the volumes of biogas and methane were also recorded.

4. Results and discussion

- The pH

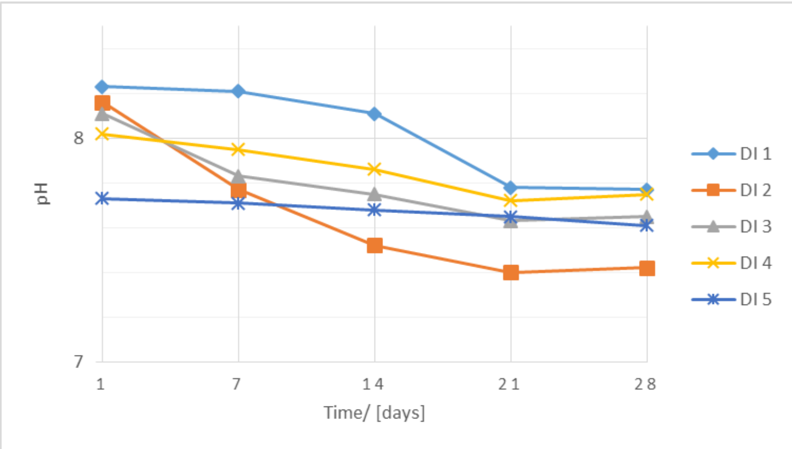


Fig. 3. Evolution of pH in all five digesters.

Fig. 3 shows that the pH begins with values above 8 in all digesters except in DI 5. The alkalinity of the medium during the first days is explained by the fact that sludge contains a lot of metals [13]. Then the pH begins to decrease until reaching a neutral pH for which the decomposition of the substrate begins. This causes fatty acids to form and accumulate in the medium during the first week of digestion in all digesters. The pH value remains above 7.6 in digesters DI 1, DI 3, DI 4, and DI 5 until the end of digestion. However, in digester DI 2, the pH value is lower than 7.6 after 10 days of digestion, reaching its minimum value of 7.4 (optimal value for anaerobic digestion) at the end of digestion. These pH values are attributed to the consumption of volatile fatty acids and the depletion of organic matter. These observations are similar to those previously reported by N. M. S. Sunyoto et al. [14].

- The ratio of volatile fatty acid (VFA) to complete alkalimetric titer (CAT)

Formation of volatile fatty acids (VFA, in meq/L) is an intermediate stage during methane fermentation. The accumulation of these acids slows down the activity of methanogenic bacteria and can even block the fermentation process. Complete alkalimetric title (CAT, in meq/L) represents the dosage of carbonates and bicarbonates, responsible for the buffering capacity of the fermenter vis-Ã -vis organic acids and volatile fatty acids.

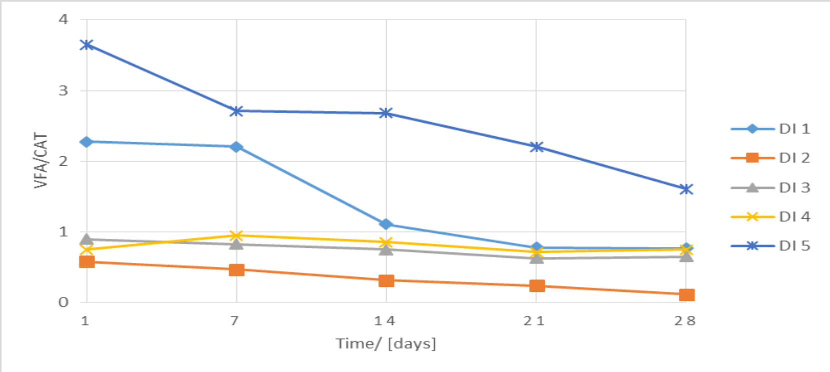


Fig. 4. Evolution of the ratio VFA/CAT in all five digesters.

Fig. 4 shows that in digester DI 1 the ratio of volatile fatty acid (VFA) to complete alkalimetric titer (CAT) varies between 3.55 and 1.5 throughout the whole duration of the experiment, which can be explained by the accumulation of significant quantities of volatile fatty acids (VFAs). Their accumulation has negative effects on the progress of anaerobic digestion. The same observations are made in the digesters DI 3, DI 4, DI 5, with a decrease in the VFA/CAT ratio after the first week, but this still remains greater than 0.6, particularly in digester DI 2 where values varied between 0.5 and 0.1 from the third day until the end of the experiment. Identical observations have been reported by S. Begum et al. [15]. This confirms that the methanation process worked smoothly.

- The biogas

Fig. 5 clearly shows that digester DI 1 produces a maximum volume of biogas of 95 mL/g VS on the seventh day, and then begins to decrease rapidly after two weeks of anaerobic digestion. The same observation was made for DI 3 digester. In digester DI 4, small volumes of biogas were recorded, between 15 and 40 mL/g VS at most per day, throughout the entire duration of the experiment. In addition, the production of biogas in digester DI 5 was zero during the first 6 days of the experiment. However, on the 10^{th} day, it reached the maximum volume of 20 mL/g VS, but went back to zero again on the 23^{rd} day until the end of the experiment.

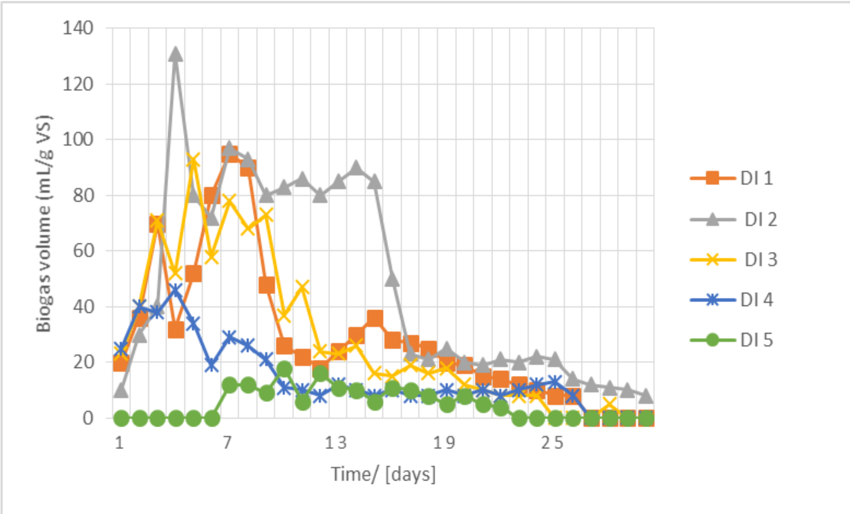


Fig. 5. Evolution of the volumes of biogas produced in all five digesters.

This can be explained by the fact that the anaerobic digestion could not take place in this digester. As for digester DI 2, the maximum volume of biogas of 135 mL/g VS was reached after four days of anaerobic digestion, but began to decrease after 17 days of anaerobic digestion; this can be attributed to the depletion of organic matter and the lack of nutrients. These results are similar to those previously reported by A. Grosser et al. [16].

- Methane

Fig. 6 shows that the maximum volume of methane produced by digester DI 2 was 98 mL/g VS on the fourth day, and then it stabilized between 80 and 55 mL/g VS until the 16th day.

Afterwards, it started decreasing beyond the 17th day. Similarly, methane volumes with less significant variations, between 20 and 40 mL/g VS, were recorded daily in digesters DI 1, DI 3, and DI 4. Note that no methane was produced during the first and last weeks in DI 5 digester, with volumes less than 15 mL/g VS during the other days (cessation of the methanisation process).

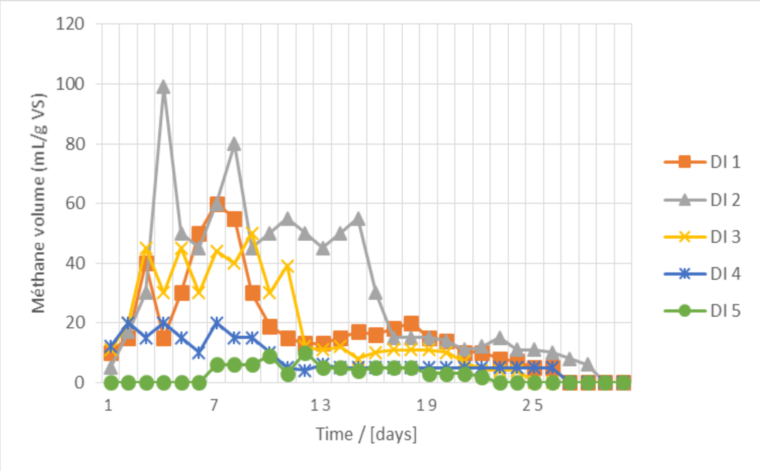


Fig. 6. Evolution of the volumes of methane produced in all five digesters.

- *Accumulation of biogas and methane volumes*

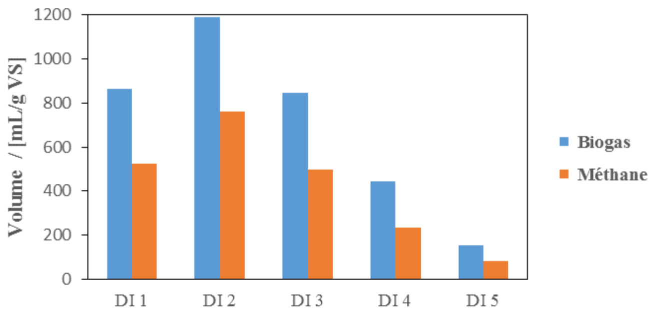


Fig. 7. Accumulation of biogas and methane volumes produced in all five digesters.

In order to determine the quantities of biogas and methane produced in each digester, the different volumes produced were added up. The largest volumes of biogas (1439 mL/g VS) and methane (909 mL/g VS) cumulated were recorded in digester DI 2. These quantities testify to the good progress of methanization. On the other hand, the smallest volumes were observed in digester DI 5, with 51mL of biogas and 80 mL/g VS of methane (poor anaerobic digestion).

- *Characterization of substrates and digestates*

Table 3

Substrate characterization before and after digestion

Characteristics		DI 1	DI 2	DI 3	DI 4	DI 5
pH	Substrate	8.23	8.23	8.11	8.02	7.51
	Digestate	7.59	7.42	7.43	7.46	7.47
Dry matter content (%)	Substrate	16.86	14.86	11.52	18.62	21.87
	Digestate	10.7	12.98	12.4	14.58	18.8
Organic matter content (%)	Substrate	75.74	85.56	79.22	56.89	42.83

	Digestate	56.21	39.63	56.66	50.22	39.98
Total chemical oxygen demand (g/l)	Substrate	21.33	32	16	42.66	58.66
	Digestate	18.64	11.66	7.66	39.33	52.83
Soluble chemical oxygen demand (g/l)	Substrate	5.33	5.66	10.33	2.66	29.33
	Digestate	4.25	2.33	9.66	2.33	26.545

Table 3 indicates that the organic matter degradation occurred at the end of digestion in all digesters but in different ways. The greatest difference between the organic loading rate of the substrate and that of the digestate was observed in digester DI 2; it was estimated at 45.93%, which indicates a good progress of the anaerobic digestion. The smallest difference was recorded in DI 5 digester; it was found to be 2.85%, which suggests a poor anaerobic digestion, as is clearly shown in Fig. 8.

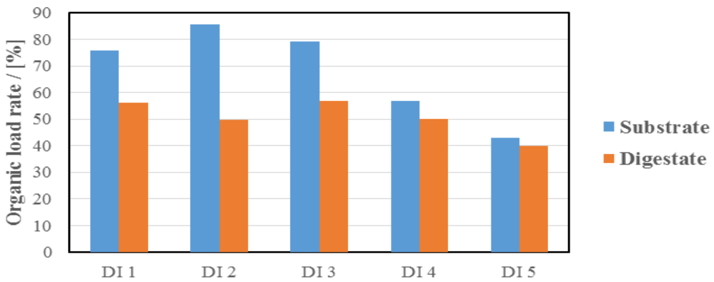


Fig. 8. The organic loading rate before and after digestion in all five digesters.

A greater consumption of the total chemical oxygen demand (COD_T) and soluble chemical oxygen demand (COD_S) was noted in digester DI 2; this is confirmed by the difference found between the COD of the substrate and that of the digestate (a medium very favorable to methanogenic bacteria). This consumption was lower in the other digesters, and in particular in digester DI 5 which contained only sludge (a medium very favorable to methanogenic bacteria), as shown in Fig. 9.

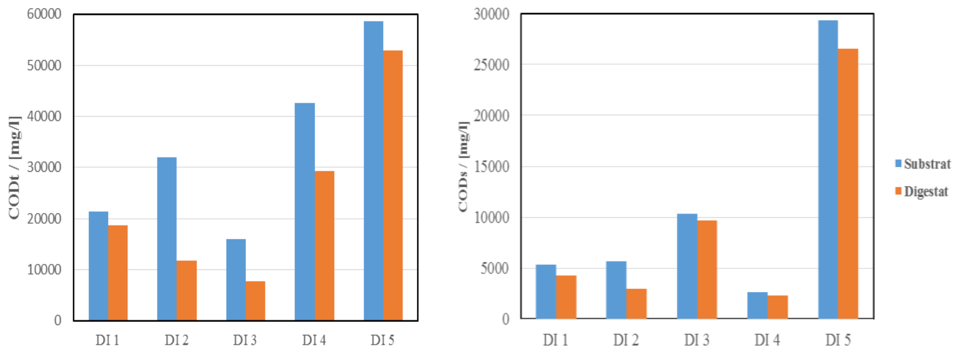


Fig. 9. Total chemical oxygen demand (COD_T) and soluble chemical oxygen demand (COD_S) before and after digestion in all five digesters

5. Conclusions

The aim of this study was to study the effect of different proportions of sludge and dromedary manure from the region of Adrar of southwest Algeria on the production of biogas and methane. It was found that the mixture of 25% dromedary manure and 75% mud gives the largest volumes of biogas (1439 mL/g VS) and methane (909 mL/g VS), with a good consumption of the chemical oxygen demand (32000 - 11666 mg / l), and a significant consumption of organic matter of about 45.93%. As a conclusion, it is highly recommended to use 25% of dromedary manure and 75% of sludge when feeding the batch digester. This will allow a good progress of the anaerobic digestion and will also induce an optimal energy exploitation of the substrate.

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