EFFECT OF ORGANIC LOADING RATES ON METHANE PRODUCTION USING HOUSEHOLD WASTE

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In order to optimize the organic loading rate and exploit it on a pilot scale, organic wastes from the slaughterhouse in the region of Adrar (Southwestern Algeria) were used for laboratory methane production by anaerobic digestion using a continuous digester with total and reaction volumes of 14 L and 12 L, respectively. Five different organic loading rates (OLRs), i.e. 1; 1.5; 2; 3 and 4 g vs / L / d, were used with the addition of 500 mL of substrate each day, for the same hydraulic retention time of 21 days, and in the mesophilic range (37± 2°C). The pH, the ratio of volatile fatty acids to the total alkalimetric titer, the volumes of biogas and methane determined by the biochemical methane potential testing method were monitored during all the experiments. The results obtained showed that the best volumes of biogas and methane were 81 L and 40 L, respectively; these volumes were reached with the organic loading of 2 g vs / L / d with a significant consumption of organic matter, of the order of 55.22%.

Keywords: Household waste, Continuous digester, Methane, Organic loading rate

1. Introduction

Today, solid wastes cause huge damage to the environment and to humans as well. Given the increasing energy needs of humans throughout the ages, and in order to find a viable solution to get rid of the large amounts of waste, it has proved very interesting and challenging to consider the process of anaerobic digestion, which promises to be one of the most suitable solutions to create value from organic waste.

Anaerobic digestion involves a series of processes by which microorganisms break down biodegradable organic matter (substrate) in the absence of free molecular oxygen (O_2) [1]. Indeed, organic matter is mainly transformed into biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2), as well as new bacterial cells [2]. Anaerobic digestion is a process that takes place in three successive stages; the first one is a hydrolysis step in which organic compounds, such as polysaccharides, proteins and fats, are hydrolyzed by

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extracellular enzymes [3,4]; the second is the acidification step during which the products of hydrolysis are converted into H_2, formate, acetate and volatile fatty acids (VFAs) with high molecular weight [5]; finally, the third stage is the one that produces biogas, a mixture of carbon dioxide (CO_2) (27-45%) and methane (CH_4) (45-80%), along with H_2 (1-10%), formate and acetate [6], [7].

Biogas, which is a mixture primarily consisting of CH_4 and CO_2, can be used as a clean renewable energy source for cooking, generating heat and electricity [8]. Moreover, refined biogas can also be used as a vehicle fuel [9]. It is worth mentioning that it is possible to act on several factors of influence on the process of anaerobic digestion in order to improve the biogas yield, and particularly the methane yield. These factors include the average organic loading rate (OLR) and the hydraulic retention time (HRT) [10], [11]. The city of Adrar, which is located in the south-west of Algeria, produces 18,392.35 tons of household waste per year. This considerable amount of waste is collected without any treatment and with no valorization. The aim of the present work is to valorize household waste by the process of anaerobic digestion, and to know the effect of the different organic loading rates (OLRs) on biogas production and on the methanogenic potential as well. This operation allows exploiting the results obtained on a laboratory and a pilot scale.

2. Material and methods

Description of the experimental setup

The continuous digester is a plastic tube, which is 20 cm in diameter and 45 cm long, hermetically sealed on both sides, with a total volume of 14.137 L and a reaction volume of 12 L. In addition, two other tubes, each 4 cm in diameter, were placed on the right and left sides; the first one is used to introduce the organic matter and the other to bring it out. In addition, two valves were added to the device; the first one was placed at the top and connected to the balloon for the collection of the biogas produced by the digester, and the second at the bottom for emptying the digester [12], as illustrated in Fig. 1.

The fermentation temperature was controlled by means of a water bath at the temperature of 37±2°C; then, the biogas produced was gradually transferred into the balloon from where it passed to the measuring and filtering system.

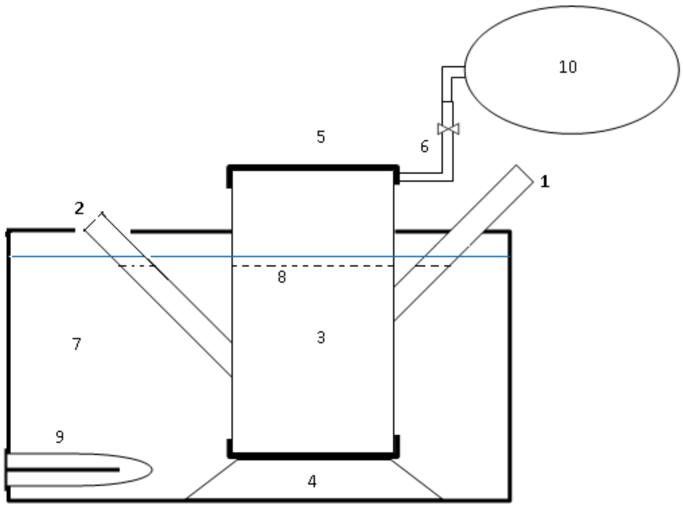

Fig. 1. Experimental device of the continuous digester at laboratory scale:
(1) Substrate (input), (2) Digestate (output), (3) Body of digester, (4) Support, (5) Lid (cover), (6) Biogas digester outlet, (7) Water bath, (8) Substrate level, (9) Electrical resistance, (10) Balloon for recovering biogas.

The substrate

The substrate considered in this study consists of household waste that had previously been generated by several houses and restaurants in the town of Adrar. After sorting, it was found that the selected substrate consists mainly of organic wastes, such as peelings of onions, potatoes, carrots, beets, salad and artichokes, which afterwards are cut into small pieces to ensure a good homogenization of the sample.

The inoculum

The inoculum used comes from a digester that has been running for more than a month; it mainly contains cow dung brought from one of the farms around the town of Adrar.

Analyses and measurements

The volume of biogas produced was measured by evaluating the volume of displaced liquid. A saturated solution (NaCl 10 g/L pH=2) was used to minimize the dissolution of CO_2, and the filtration of biogas was carried out using a solution of 3 M NaOH per liter bio-methane potential (BMP) test [13], as shown in Fig. 2.

The pH was measured using a HANNA HI 8314 pH meter. On the other hand, the dry matter content, the organic matter content, the chemical oxygen demand (COD), the volatile fatty acids (VFAs) and total alkalinity were determined by the standard method [14]. In addition, analyses of the chemical oxygen demand (COD) were performed after centrifugation and filtration of the supernatant through a 0.45 μm filter [15].

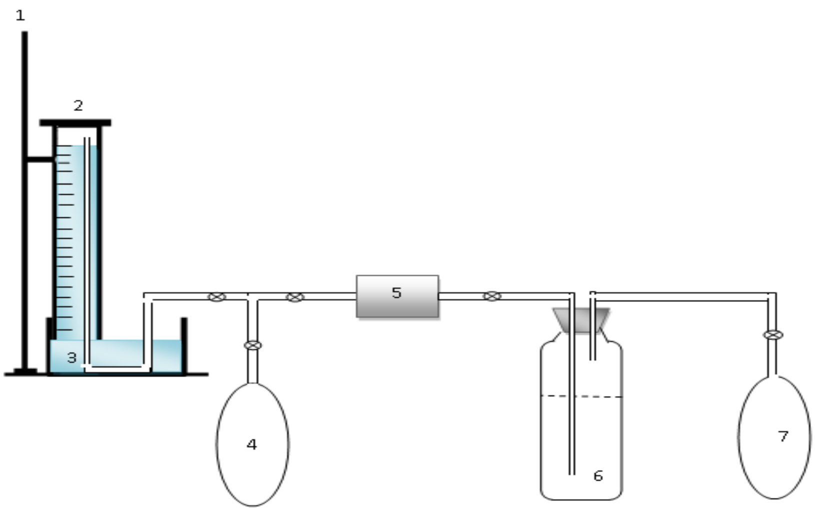

Fig. 2. Bio-methane potential (BMP) test: (1) Stand, (2) Inverted graduated cylinder, (3) Saturated solution (10 g/L of NaCl), (4) Unfiltered biogas, (5) Vacuum pump, (6) CO_2 filtration (3 M NaOH solution), (7) Filtered biogas.

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) is 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, after quantification the biogas is pumped (5) into a solution of 3 M NaOH) (6) to remove the CO_2, finally we obtained a pure methane (7) which is quantified by the same method.

3. Operating mode

During the first day, the continuous digester started with the previously described substrate and inoculum with the substrate / inoculum ratio of 1/2 [16,17], and organic load of 1 g/L. After the decrease in the volume of biogas, the digester was fed with 500 mL of substrate for 21 days. The same method was repeated for the other organic loading rates (OLRs), 1,5; 2; 3 and 4 g vs/L/d, successively, for a unified residence time of 21 days (pH adjustment with NaOH solution in the first three days for each experience). Furthermore, three tests were carried out for the same organic loading, and the result taken into account was the average of the three values from the three tests. Operating parameters, such as pH, volatile fatty acids (VFA), total alkalinity, biogas and methane volumes, and substrate characteristics prior to each experiment (before use) are shown in Table 1.

Table 1.

Initial characteristics of the substrate

Organic load (g vs/L/d)	pH	Humidity level (%)	Dry matter content (%)	Organic matter content (%)	Chemical oxygen demand (COD) (mg/L)
1	6.92	88.31	11.7	94.06	13250
1.5	6.61	86.96	13.4	94.21	15072.67
2	6.32	86.04	15.8	96.31	14151.09
3	6.12	79.56	16.23	97.2	15821.33
4	5.88	81.89	17.02	97.4	15630.02

4. Results and discussion

The pH

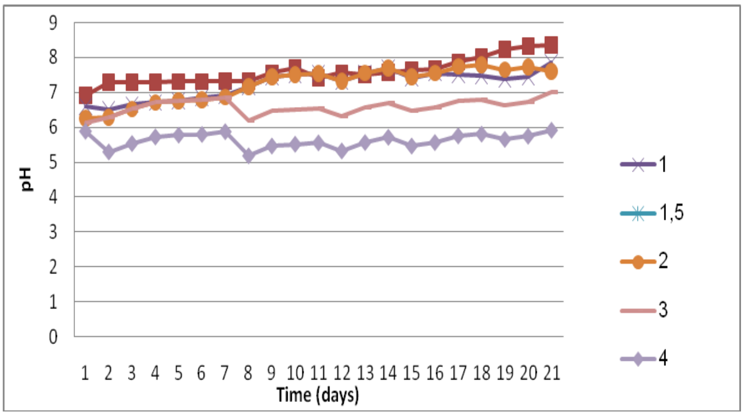

Fig. 3. pH values as a function of time for the five OLRs.

It can clearly be seen from the curves in the Fig. 3 that the pH varies between 6.5 and 8 for the OLRs 1; 1.5; and 2, with an acidic medium during the first days; this can be explained by the decomposition of the substrate, the formation of fatty acids and their accumulations in the medium. After that, the pH starts increasing to an eventually approach the neutral point, and this is explained by the production of ethanol in the medium. After the tenth day, the pH stabilizes between 7 and 7.5, which is an optimal range for the anaerobic digestion; this pH stability may be explained by the consumption of volatile fatty acids (VFAs) and the depletion of organic matter [18], [19].

For the organic loading rates (OLRs) 3 and 4, the pH does not exceed the values 7 and 6, respectively, in both tests; this may be attributed to the accumulation of fatty acids for most of the time.

Volatile Fatty Acids/Total Alkalinity (VFA/TA) ratio

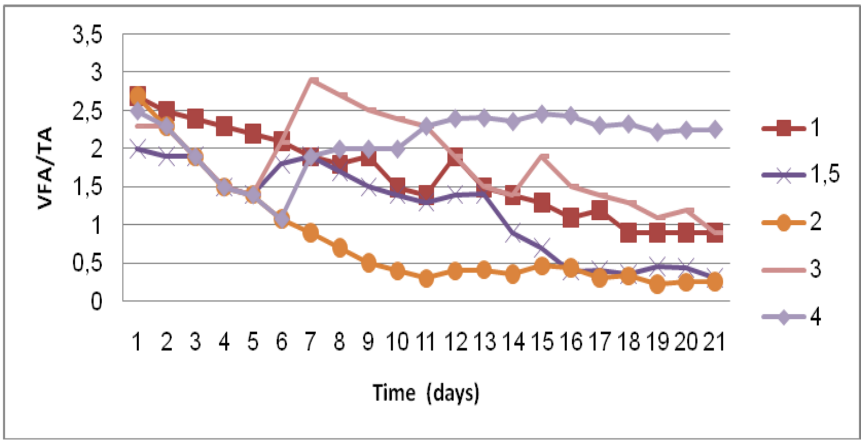

Fig. 4. Evolution of the VFA/TA ratio as a function of time, for all five OLRs

Fig. 4 shows that with the organic loading rates (OLRs) 1, 3, and 4, the ratio VFA/TA varies between 0.9 and 2.7, which explains the presence of significant amounts of volatile fatty acids (VFAs). The accumulation of these acids has a negative impact on the progress of the anaerobic digestion. The same scenario occurs again for the VFA/TA ratio with OLRs 1 and 1.5. However, the values of this ratio are less than 0.5 after the tenth day for OLR 2 and after the fifteenth day for OLR 1.5, which explains the good progress of the anaerobic digestion process [20.21].

The volumes of biogas and methane (CH_4)

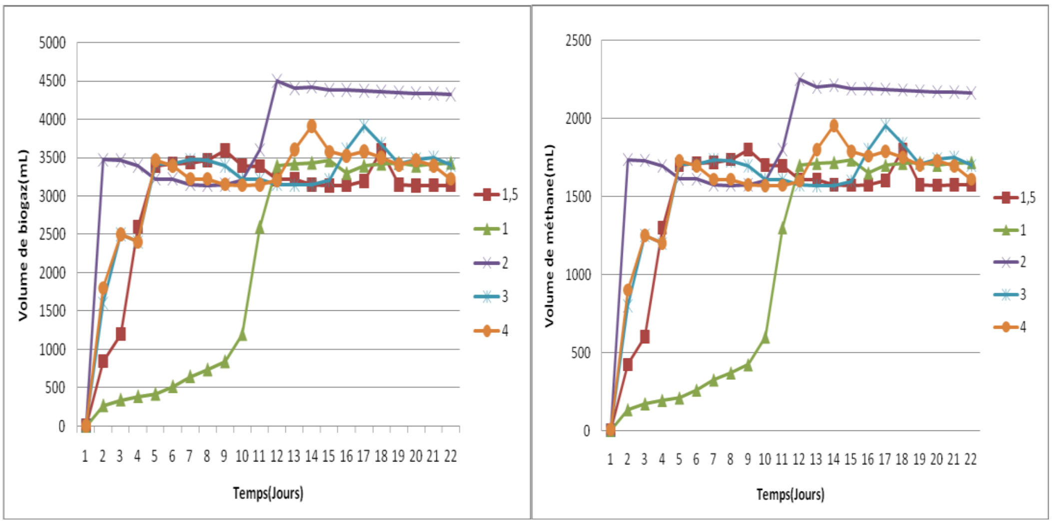

Fig. 5. Volumes of biogas and methane produced as a function of time, for all five OLRs.

Fig. 5 indicates for OLR 1, that there is a slow growth period in the first 10 days, which explains the time that bacteria need to adapt to the new medium and then start producing gas. While in other experiments there has been immediate production of biogas since the first day, because the bacteria have recognized the medium, the maximum biogas volume produced is 3500 mL/d on, with a maximum CH_4 volume of 1550 mL/d, and for OLR 1.5 the maximum biogas volume produced is 4000 mL/d, with a maximum CH_4 volume of 2050 mL/d.

For the organic loading rate OLR 2, a period of acute growth was observed in days 11 to 12 and this is explained by the beginning of the methanogens phase and with an ideal organic loading rate. The bacteria produced the maximum biogas amount as well as the maximum volume of methane (4000 mL/d of biogas and 2550 mL/d of methane) [22,23]. On the other hand, for the OLRs 3 and 4, the volume of biogas reaches the maximum value of 4250 mL/d and that of CH_4 the maximum of 2125 mL/d; this takes place after 16 days for OLR 4 and after 20 days for OLR 3.

The decrease in gas volumes with OLRs 1 and 1.5 indicates that the organic load is insufficient for a good fermentation. The reverse situation is observed for OLRs 3 and 4 for which the organic loading is in excess. It should be noted that the ideal charge rate is 2 g vs/L/d.

Volume accumulation

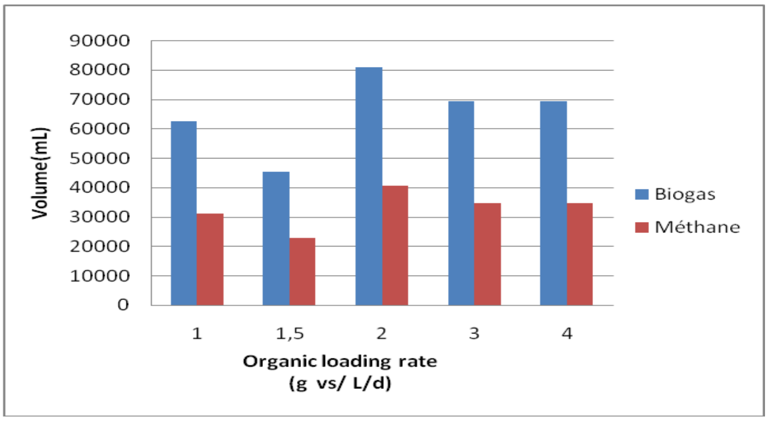

Fig. 6. Volumes of biogas and methane accumulated at the end of each experiment.

In order to determine the quantities of biogas and methane produced by the digester for the five OLRs, it was decided to add up the volumes produced during each experiment. The largest volumes of biogas and methane, accumulated with OLR 2, were 81145 mL and 40572.5 mL, respectively.

Characterization of the substrate after digestion

Table 2

Final characteristics of the substrate after each experiment

Organic loading rate (g vs/ L / d)	pH	Moisture rate (%)	Dry matter content (%)	Organic matter content (%)	Chemical oxygen demand (COD) (mg/L)
1	8.35	89.56	10.02	62.66	16629.66
1.5	7.87	91.83	09.04	59.53	17122
2	7.61	92.06	7.94	41.09	20812.33
3	7.02	87.59	11.66	71.31	5852
4	5.91	88.98	12.31	72.22	4391.67

According to Table 2, the final chemical oxygen demand (COD) for OLR 1 (16629.66 mg/L) is greater than that obtained on the first day of the anaerobic digestion (13250 mg/L). This difference in volume indicates the beginning of the degradation process of the substrate which consists mainly of macromolecules (hydrolysis and acidogenesis phase) [24], [25]. A similar remark is made for OLR 1.5 and OLR 2; indeed, the final chemical oxygen demand is maximum (20812.33 mg/l) at the end of OLR 2 and this is explained by the degradation of the entire substrate [26,27]. This is well confirmed by the volume of biogas produced during that period. After the OLR 3, the chemical oxygen demand begins to decrease and reaches its minimum value, which is of the order of 4.91 g/L, at the end of OLR 4, with a very low degradation rate of the organic charge [28].

5. Conclusions

The study of the different average organic substrate loadings for feeding a continuous digester with a reaction volume equal to 12 L indicates that, for a better consumption of organic matter and maximum yields of biogas and methane, an average organic loading rate of 2 g vs / L / d is recommended. This should give a maximum volume of biogas (81 L) and a maximum volume of CH_4 (40 L). The volume efficiency is 83.82 liters of biogas / L of digester / day, with a maximum organic matter consumption of 55.22 %. On this basis, it is recommended to feed the continuous digester on a pilot scale with an average organic loading rate of 2 g vs / L / d, for optimum energy use of this type of waste.

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