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Optimization of Hydraulic Retention Time for the Methanisation of Household Waste in the Town of Adrar(the south-west of Algeria)

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Abstract : Household waste from the town of Adrar, in south-western Algeria, has been valorized by anaerobic digestion into a continuous digester, with 12 L reaction volume, and five different hydraulic retention times(HRTs), namely 7, 14, 21, 28 and 35 days, with the same substrate concentration of 16 g / L of total solids (TS), and at the mesophilic temperature of 37°C. The pH, VFA/TA ratio as well as the biogas and methane volumes was recorded throughout the experiment by Biochemical Methane Potential (BMP). The results obtained showed that the best feeding for continuous digesters is the one reached after a residence time of 21 days. The latter ensures a volume efficiency of 83.82 L of biogas / L digester / day and an accumulation of a maximum biogas volume (35L) and a maximum methane volume (23L). The consumption of organic matter is fairly good and is around 51.4%, more than other hydraulic retention times.
Keywords : Household waste; Continuous digester; anaerobic digestion; Hydraulic retention time; Town of Adrar.

Introduction

In recent years, Algeria has endeavored to create the conditions for a better approach in the management of environmental issues through numerous conservation and protection mechanisms. Demographically, Algeria had a population of 39.5 million inhabitants in the year 2015; the population growth in the region has resulted in a significant increase in the volume of household waste. Due to the damage caused by household waste both to the environment and to humans, and given the increasing energy needs of humans throughout the ages, in order to find a solution to these two global problems, the scientists are trying to clarify the importance of the process of anaerobic digestion as a solution to the two problems together.

Anaerobic digestion is a biological process in which a group of microorganisms biodegrade the organic matter (substrate) in the absence of free molecular oxygen (O_2)[1, 2]. The organic matter is mainly transformed into a mixture of methane (CH_4), carbon dioxide (CO_2, biogas), as well as new bacterial cells[3, 4].The process of anaerobic digestion consists of three steps. The first one is a hydrolysis step in which the organic compounds, such as polysaccharides, proteins and fats, are hydrolyzed by extracellular enzymes; the second step is that of acidification where the hydrolysis products are converted into H_2, formate, acetate and volatile fatty acids

having a high molecular weight. The third step involves the formation of biogas which is a mixture of carbon dioxide (CO_2, 27 - 45%), methane (CH_4, 45 - 80%), and hydrogen (H_2, 1 - 10%)[5, 6].

Biogas is a renewable energy source. It can be used for the generation of heat and electricity; it may also be used, in a refined form, as a biofuel[7, 8]. Several parameters, such as the average organic load and the hydraulic retention time, can be used to influence the anaerobic digestion, in order to significantly improve the biogas and methane yields [9, 10].

The hydraulic retention time (HRT) is the average time during which the liquid organic substrate is maintained in the digester[11]. A retention time of 5 days is considered as short because it is not sufficient to ensure a stable digestion[12], and 25 days of hydraulic retention time (HRT) is the recommended period to obtain biogas and methane[13]. The 9-day period is considered as an optimum hydraulic retention time for the anaerobic digestion of petrochemical wastewater [14]. The duration of 60 to 90 days of hydraulic retention is generally recommended for the production of domestic biogas in rural areas[15].

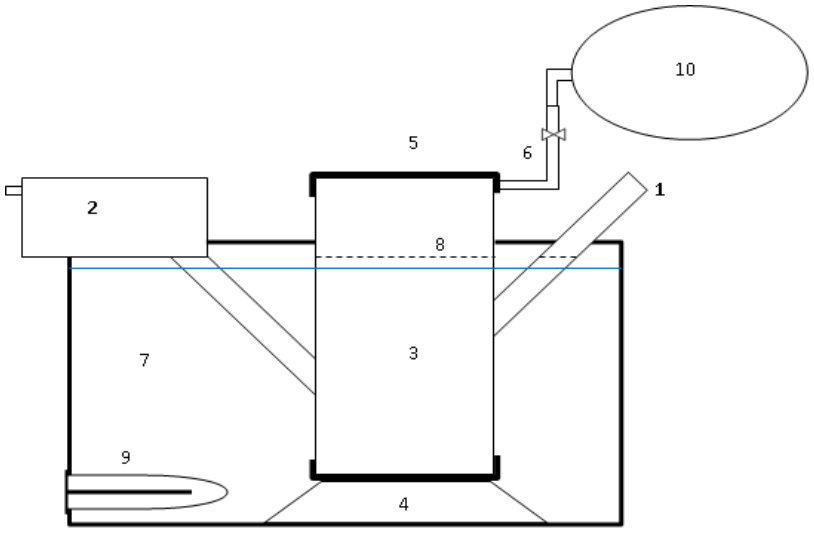
In Adrar, a town located in south-west Algeria, the amount of 18392.35 tons of household waste is generated annually. This waste contains more than 62 % of organic matter. This impressive amount of waste is collected without any treatment and no recovery.

The objective of this work is to adopt a better residence time (HRT) for the anaerobic digestion of household waste in the town of Adrar, and also to exploit these results when using high capacity digesters (pilot scale) in order to recover the maximum of energy from this waste.

Material and method

Description of the experimental device

The continuous digester is a plastic tube with a diameter of 20 cm and a length of 45 cm, hermetically sealed on the top and bottom ends, having a reaction volume of 12 L. Two 4 cm diameter tubes were installed on the right and left sides; one for the introduction of the organic matter and the other for the output. In addition, two valves connected to the flask were placed, one at the top of the device, for collecting the biogas produced by the digester and the second at the bottom for emptying the substrate, as shown in Fig. 1. The fermentation took place in a water bath, at the temperature of 37 °C[16]. Then, the biogas produced was transferred from the flask to the measuring system, where CO_2 is eliminated.



(1) Inlet – (2) outlet – (3) Digestion tank – (4) Digester base – (5) Lid – (6) Collecting biogas pipe – (7) water bath – (8) substrate level – (9) Electric resistance with thermostat (10) Balloon for the recovery of biogas

Figure 1: Continuous digester diagram

The substrate

The studied substrate consisted of household waste that was generated by several houses and restaurants in the town of Adrar. After sorting, the remaining substrate was composed of organic waste such as peelings of onions, potatoes, carrots, beets, salads and artichokes. These were then cut into small pieces to ensure a good homogenization of the sample.

The inoculums

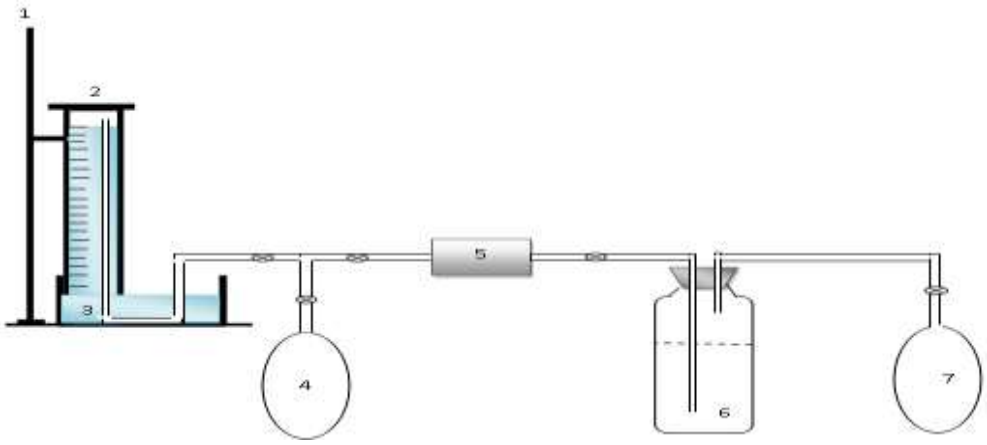
The inoculum used comes from a digester, which has been running for more than a year; it contained cow dung from one of the farms near the town of Adrar. The characteristics of this cow dung are given in the following table (refer with: Table 1).

Table 1: Characteristics of the substrate and inoculum before launching the experiment

Analytical parameters	Units	Substrate	Inoculum
pH		6,92	5,81
Humidity level	%	88,31	78,25
Total Solids (TS)	%	11,7	21,75
Volatile Solids (VS)	%	96,06	94,01
Mineral content	%	3,94	5,99
Chemical Oxygen Demand (COD)	mg/l	13227,51	21744,79

Analyzes and measurements

The volume of biogas produced was measured by the displaced liquid method[17, 18]; a saturated solution of NaCl (10 g / L, pH = 2) was used in order to minimize the dissolution of CO_2. The removal of CO_2 was performed with the help of NaOH solution (3M / L) (Biochemical methane potential (BMP))[19]; refer with: Fig. 2.The pH was measured using a pH-meter model HANNA HI 8314. Moreover, total solids (TS), volatile solids (VS), chemical oxygen demand (COD), concentration of volatile fatty acids (VFAs), and the total alkanility (TA), were determined by the standard method[20]. The analyses of the chemical oxygen demand (COD) were carried out after centrifugation and filtration at 0.45 µm of the supernatant[21].



(1) Support - (2) inverted test tube - (3) Saturated solution (Nacl 10g/l pH=2) - (4) Unfiltered Biogas (5) Vacuum pump - (6) CO2 filtration (solution of NaOH (3M/l)) - (7) Filtered Biogas.

Figure 2: Diagram of a device for measuring biogas and Biochemical Methane Potential test

Operating procedures

The continuous digester started with the substrate and inoculum previously described, with a substrate/inoculum ratio equal to 1/2 [22, 23]. The feed to the continuous digester was carried out with the same substrate and same parameters, with five hydraulic retention times, namely 7, 14, 21, 28 and 35 days,

successively. Similarly, a control digester, containing only the inoculum, was also launched. Three tests were conducted with the same hydraulic retention time (HRT), and the mean of the three results was considered. The operating parameters such as pH, VFA, TA, biogas and methane volumes were well monitored.

Results and discussion

The pH

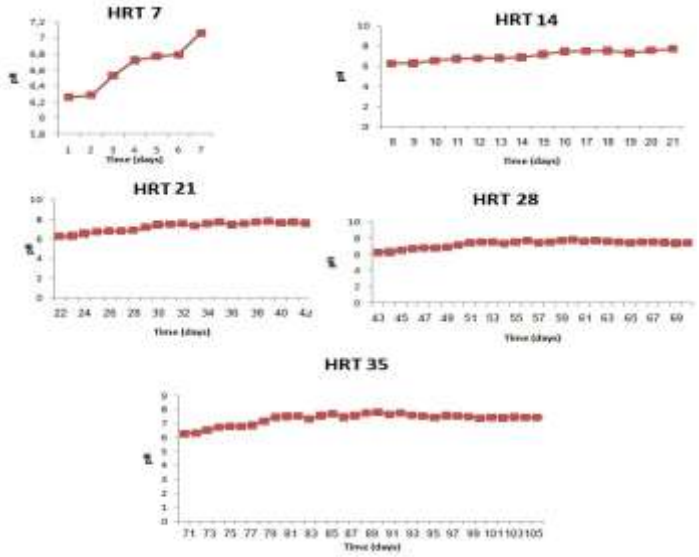


Figure.3: pH evolution in the five HRTs

The optimum pH value for a good anaerobic digestion was close to neutrality that is a pH between 6.5 and 7.5[24]. According to Figure 3 the pH evolution curve for the 7-day hydraulic retention time (HRT 07) varied between 6.26 (day one) and 7.02 (day 7); The acidity of the medium during the first days was due to the decomposition of the substrate and the formation of fatty acids and their accumulation in the medium, and this led to an increase in the pH which approached neutrality. Thus, there was production of ethanol in the medium. For the other HRTs 14, 21, 28 and 35 days, a similar pH curve was seen to begin with the value 6; it increased during the first ten days, then stabilized between the values 7 and 7.5 (optimal value for anaerobic digestion). According to Raposo F. and Borja R.[25] on one hand and Yacob S. and Shirai Y. on the other[26], this stability is due to the consumption of volatile fatty acids (VFAs) and the exhaustion of the organic matter.

The VFA/TA ratio

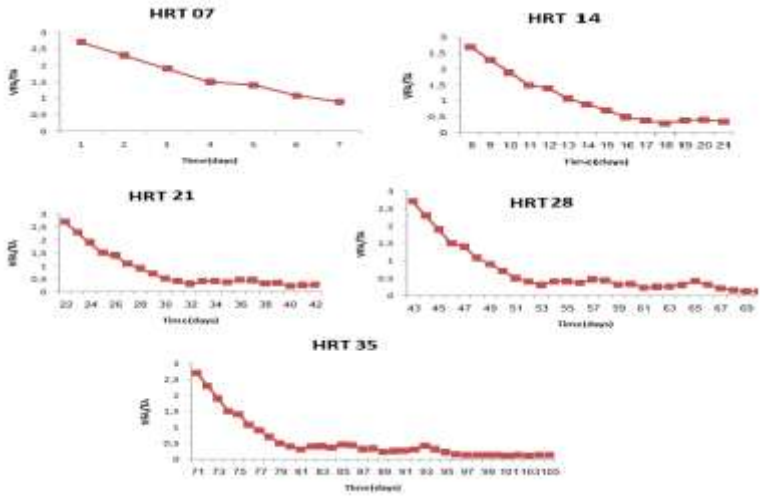


Figure 4: VFA/TA ratio change in the five HRTs

Figure 4 shows that for the 7-day hydraulic retention time (HRT 07), the VFA/TA ratio varies between 2.7 and 0.9, and this is explained by the large amounts of volatile fatty acids that have accumulated. Their accumulation has a negative influence on the progress of methanization. The same thing happens with the VFA/TA ratio for HRT 14, but with values 0.5 smaller after the tenth day. The shape of the HRT 14 curve is similar to that of the curves of HRTs 21, 28, and 35. A decrease in the VFA/TA ratio by a value smaller than 0.5 was noted after the tenth day; this ratio varied between 0.5 and 0.1 until the end of the experiment. These same observations were reported by Chen TH and Huang JL [27] on one side and Nordberg A. et al. [28]on the other. The results obtained confirmed the good progress of the methanization process.

The volumes

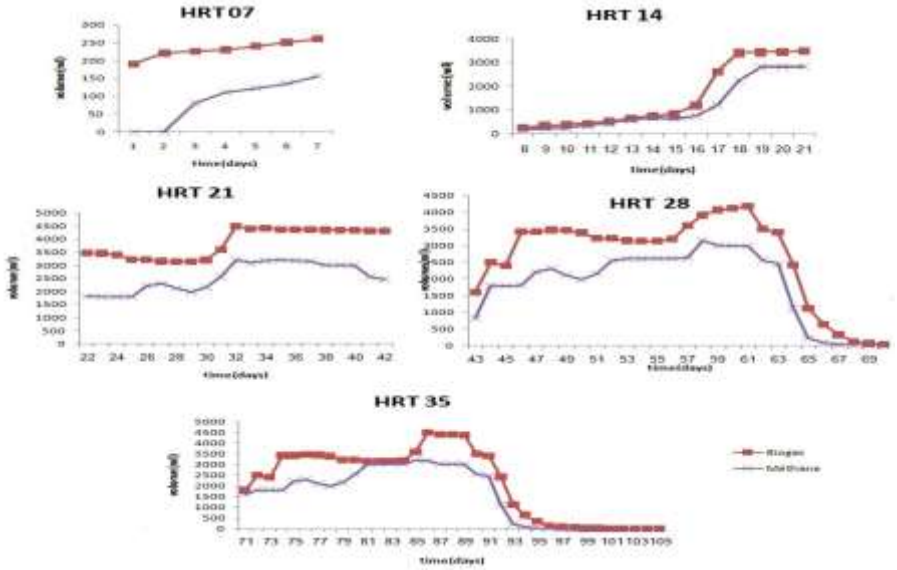


Figure 5: Evolution of biogas and methane volumes in the five HRTs

According to Figure 5, at the hydraulic retention time of 07 days (HRT 07), the maximum volume of biogas was 260 ml and that of CH4 was 156 ml. At HRT 14, the volume produced was 3450 mL for biogas and 2200 mL for CH4, after 10 days of methanization. These values remained stable thereafter. Almost identical values were recorded at the hydraulic retention times of 21, 28, and 35 days (HRT 21, HRT 28 and HRT 35). Maximum volumes of 4500 mL of biogas and 3210 mL of CH4 per day were recorded at HRT 21. These volumes remained relatively stable during the last ten days (very good methanization conditions). There was a decrease in the volumes of biogas and CH4 at HRT 28 and HRT 35, after 20 days. They became equal to zero on the twenty-sixth day at HRT 28, and on the twenty-fifth day at HRT 35. This may be explained by the depletion of organic matter and the absence of nutrients, similar findings have been reported by Boutouta I. et al.[29] on one side and Djaâfri M. and Khelifi M.[30] on the other.

Cumulative volumes

The quantities of biogas and methane (CH_4) accumulated during each residence time were found by subtracting the volume of biogas produced by the control digester from that produced by the main digester; the same operation was repeated with methane. After a hydraulic retention time of 35 days (HRT 35), a biogas volume of 46322mL and a methane volume of 29863mL were obtained.

The largest volumes of biogas and methane were accumulated at the hydraulic retention time of 21 days (HRT 21); these volumes were 35223mL and 23819mL, respectively. It is worth noting that these values remained almost constant for HRT 28 and HRT 35, as shown in Figure 6.

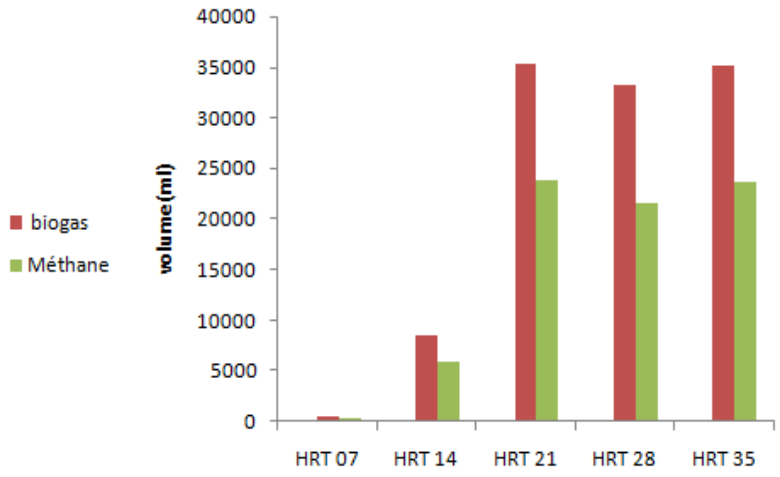


Figure 6: The cumulative volumes (biogas and methane) with the different reside time

Characterization of the substrate after digestion

According to Table 2, the final COD for HRT 07 (13227.51 mg/L) is higher than the COD on the first day of anaerobic digestion (9796.44 mg/L). This corresponds to the beginning of the degradation of the substrate, which is predominantly composed of macromolecules (hydrolysis and acidogenesis phase). The same remark can be made about the final COD for HRT 14 and HRT 21. The DCO reached its maximum value (16927.08mg/L) at the end of the 21-day hydraulic retention time (HRT 21). This is due to the degradation of the bulk of the substrate and this is evidenced by the amount of biogas produced during this period. After the hydraulic retention time of 28 days (HRT 28), the COD started to decrease to a minimum value at the end of HRT 35, which is around 4866.18 mg/L, with an organic degradation rate of 51.04%. Similar results have been reported by Alvarez, Ruiz and Gomez[31], Junqin, Dongsheng and Yanhua[32], and Chulhman, Chunyeon and Sangyong[33].Considering the volume of biogas produced during the 35-day hydraulic retention time (HRT) (HRT 35), a volume yield of 83.82 L biogas / L digester / day was obtained. This quantity is considerable in comparison with those obtained by Marouani L. and Bouallagui H.[34], and Afilal M.E. and Elasri O.[35].

Table 2: Characteristics of the substrate after each residence time

HRT (days)	pH	Total Solids (TS) (%)	Volatile Solids (VS) (%)	COD final (mg/l)
07	7,06	11,04	88,98	13227,51
14	7,71	10,49	71,69	16071,43
21	7,61	7,94	46,09	16927,08
28	7,45	7,78	45,11	6361,32
35	7.32	8,14	45,02	4866,18

Conclusion

The study of the different hydraulic retention times in a continuous digester, with a reaction volume of 12L, showed that for a good consumption of organic matter and a maximum yield of biogas and methane, the hydraulic retention time must be at least equal to 21 days; this gives a maximum volume of biogas (35L) and a maximum volume of CH_4 (23L), with a volume yield of 83.82L of biogas / L of digester / day, and a maximum organic matter consumption of the order of 51.4% .

On this basis, and in order to save time, it is advisable to opt for a pilot or semi-pilot fed continuous digester, after a residence time between 21 and 28 days, for an optimum energy use of this type of waste.

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