COMPARISON OF THE METHANE YIELD BETWEEN DIFFERENT TYPES OF ORGANIC WASTE IN THE REGION OF ADRAR, THROUGH ANAEROBIC DIGESTION

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This study was carried out on four types of organic waste, namely household waste, slaughterhouse waste, agricultural waste, and dried sludge. It was conducted in the region of El Ksour in the Wilaya (Province) of Adrar, in the southwestern part of Algeria. The present work aims primarily to valorize these types of waste and find out which ones are more profitable in terms of biogas and methane production. For such purpose, we launched four Batch-type digesters of 1L reaction volume with the four types of waste. More to the point, the concentration of substrate in the digesters is 16 g/L of organic matter and the ratio: Inoculum/Substrate is 2/1. The digestion was performed under mesophilic conditions, at the temperature of (37 ± 2 °C), with a unified hydraulic retention time of 28 days for all digesters. In support of which, biogas and methane volumes have been monitored during all the conducted experiments (by the methanogenic potential test method or BMP). Similarly, the pH values, as well as the volatile fatty acids over the complete alkalimetric titer (VFA/CAT) ratio were regularly recorded every week, while the organic matter (OM) content, the chemical oxygen demand (COD) and the biological oxygen demand (BOD_5) were measured at the beginning and at the end of the experiment.

The results obtained indicated the anaerobic digestion of the slaughterhouse waste was quite successful. This could be confirmed by the high consumption of the chemical oxygen demand (33000-10333 mg/L) and the significant quantities of biogas (1723 mL) and methane (1352 mL) produced. In addition, the amount of substrate (45.93 %) consumed was much more important as compared to the other types of organic waste used in this work.

Keywords: Methane yield, Household waste, Slaughterhouse waste, Agricultural waste, Dried sludge, El ksour in Adrar

1. Introduction

Waste-to-energy or energy-from-waste is the process of producing energy in the form of electricity and/or heat through the basic processing of many types

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of waste which can also be treated and be an essential source of fuel such as biogas and biomethane.

Waste-to-energy has been the motto of the world for the last half century, particularly now that energy has become one of the most important factors that could contribute to the development of countries throughout the entire world, particularly after the decline in fossil energy production over the past few decades. Overconsumption of this type of energy may lead to its complete dissipation in the decades to come.

It is widely acknowledged the world's population has been continuously increasing during the last half-century. In addition, the daily energy needs of people around the world are also rising accordingly, and the quantities of disposed waste are also rapidly growing. The energy-from-waste slogan has pushed researchers to propose some solutions to two problems. The first one is environmental, whilst the second is energetic. They thought about processing different types of waste produced by man, to solve the environmental problems, and use them as a raw material to produce energy that can be used by man, and hence solve the crucial problem of energy problem.

It is worth indicating that 60 % of organic matter comes from household waste produced the population of the entire world [1, 2].

For this reason, researchers around the world tried to design and develop techniques that can be utilized to convert this waste into usable energy and to protect man and Mother Nature from their negative effects.

It was revealed that one of the most efficient methods that can be employed for the valorization of this waste is the anaerobic digestion as it offers the possibility to recover the orgiastic waste and produce a green and renewable energy in the form of the biogas which is a mixture of combustible gases. Biogas is rich in methane (CH_4) and possesses a high energetic power; it can be used in numerous applications (heating, cooking), electricity (lighting) and as a biofuel [3, 4, 5].

The region of Adrar at the south-western side of the Algerian Sahara is characterised by groups of people living in villages called "Ksour", which are characterised by:

- Their large number (more than 300 Ksar);
- Very long distance between them;
- Low population density;
- Total dependence of the population on agriculture.

The above-mentioned facts make the connection of the population of Adrar to the national electricity network quite difficult and too expensive because this operation can sometimes be almost impossible as this region is known for its desert rough terrain that is generally difficult to access.

The present paper primarily seeks to compare the methane yields provided by different types of organic waste using the anaerobic digestion process in the region of Adrar. For this, it was decided to choose four types of organic waste: Household Waste (HW), Slaughterhouse Waste (SW), Agricultural Waste (AW), Dried Sludge (DS) for the same site in the region of Adrar, in order to find a solution to both the problem of the waste and energy in this region.

2. Equipment and methods

Substrates

The substrates subject to study include Household waste, Slaughterhouse waste, Agricultural waste and Dried sludge being collected in "El Ksour" of Adrar, at the south-western side of Algeria. Besides, in order to avoid aerobic degradation of the substrate and the contamination thereof by microorganisms, a drying process is carried out directly after its collection within an indirect solar dryer. Moreover, the moisture content obtained after drying is less than 07%. Afterwards, the dried wastes have been crushed in a micro-grinder so as to obtain particles smaller than 500 μm; more to the point, this grinding increases the specific surface area (developed surface of the powder per unit of mass) [6,7] which will later be stored at 4°C until they will eventually be used, as is clearly illustrated in Fig. 1.

A B C D

A : Household Waste; B: Slaughterhouse Waste; C: Agricultural Waste; D: Dried Sludge

Fig. 1. : The *Substrates*

Inoculum

The inoculum used in the present study was recovered by decantation in a batch digester operating at 37 °C for two months period through treating the dried sludge recovered from the lagoon plant of the city of Adrar. Subsequent to which, an amount of 40g of organic matter (OM) of inoculum has been introduced into each reactor used in the digestion. More to the point, according to the potential bio-methane protocol, a seven-day's reactivation and degassing operation at 37 °C has been carried out prior to the launching of experiments [8, 9]. This inoculum (pH = 8.32) has been used as an alkaline agent for adjustment purpose of the pH of the substrates. It is also an efficient methane-producing microorganism that is decisive for the quick and successful start of the anaerobic digester. The table given below summarizes the characteristics of the Inoculum.

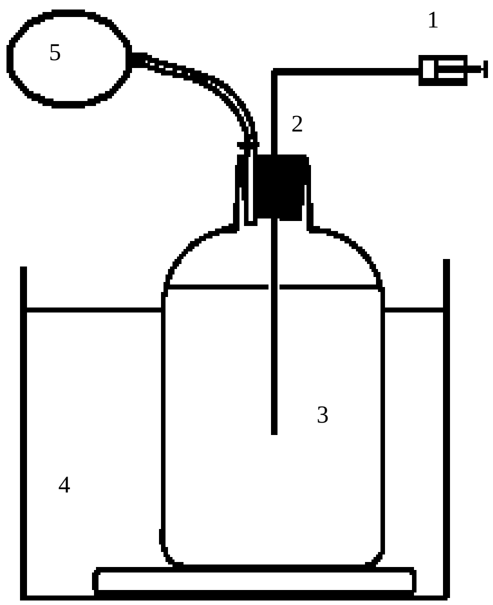
Table 1

Characteristics of the inoculum.

Parameter	Unit	Value
pH		5,81
Dry matter content	%	21,75
Volatile solid content (VS)	%	94,01
Chemical Oxygen Demand (COD)	(mg/L)	21743,33
Biological Oxygen Demand (BOD_5)	(mg/L)	15666.66

Preparation of reactors

The experimental device represents a batch type bioreactor which consists of a glass bottle whose capacity is assessed to 1 liter (800 mL of useful volume).



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

Fig. 2. Laboratory digester system.

Furthermore, two outlets were placed on its cap. The first outlet for taking samples through a syringe and the second one allows the biogas produced to escape. The bioreactor was air tightly closed to ensure that the anaerobic digestion process occurs. Note also that the temperature of fermentation of 37°C was thermostatically controlled in a water bath, as shown in (Fig. 2). Subsequently, the produced biogas is transferred by flask to the CO_2 measuring and removal system. [10, 11]

Experimental methodology

The different types of selected substrates, namely household waste (HW), slaughterhouse waste (SW), agricultural waste (AW), and dried sludge (DS), were introduced into the four batch digesters. Then, the inoculum with a (substrate/inoculum) ratio of 1/2 was added [12, 13]. However, each experiment is repeated three times and the result shall be the average of the three experiments; the initial characteristics of the substrates are shown hereunder in Table 02.

Table 02

Initial characteristics of the substrates

Parameter	Unit	Household Waste	Slaughterhouse Waste	Agricultural Waste	Dried Sludge
pH		8,22	8,21	8.01	8
Dry matter content	%	20.9	21,75	23.63	47
Volatile solid content (VS)	%	95.23	94,01	92.36	43.76
Chemical Oxygen Demand (COD)	(mg/L)	20666.6	21743,33	13522	29333,33
Biological Oxygen Demand (BOD_5)	(mg/L)	19653	15666.66	20651	14733

Analyses and measurements

The biogas and methane volumes have been updated by use of the displaced liquid method, with a saturated solution (NaCl 10 g/L pH=2) in such a manner to minimize the CO_2 dissolution; the removal of CO_2 by use of a NaOH solution (3M/L). This was achieved using the methanogenic potential (BMP) test which determines the amount of biogas and methane (CH_4) that can be produced by an input [14,15]

The pH has been measured by means of a HANNA HI 8314 pH meter, the determination of Volatile Fatty Acids (VFA) and the Complete Alkalimetric Title (CAT) have been followed-up on weekly basis by the standard APHA method [16] , the dry matter rate, the organic matter rate, the Chemical Oxygen Demand (COD) and the Biological Oxygen Demand (BOD_5) are determined before and after each experiment by means of the same method, the COD analyses are carried out after centrifugation at 0.45µm and filtration of the supernatant. [17]

3. Results and discussion

Hydrogen potential

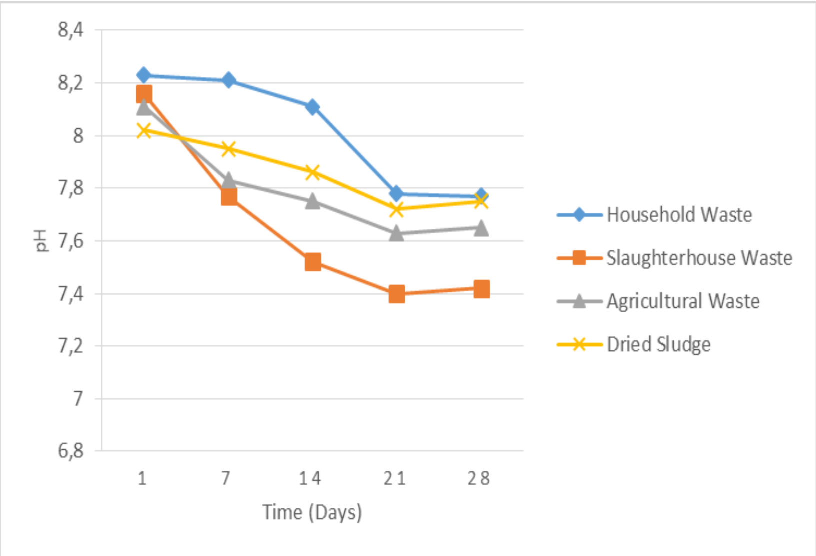


Fig. 3. Evolution of *Hydrogen potential*.

Based on Fig. 3, one may easily see that the pH in all digesters begins with quite elevated values that are higher than 8 during the first days. It should be indicated that this medium alkalinity during the first days of the process can certainly be attributed to the median metal loading [18]. Then the pH begins to drop to reach neutrality in all four digesters. This can be assigned to the decomposition of the substrate and the production of fatty acids and their cumulation within the medium at the end of the first week of digestion, in all four digesters, and specially digester containing the slaughterhouse waste (SW) whereat the pH could attain the value of 7.4, which is considered as the optimal value for the anaerobic digestion. It should also be noted that the pH values remained superior to 7.6 until the end of the digestion process in the HW, AW and AS digesters. These pH values can be explained by the important consumption of volatile fatty acids and the depletion of organic matter [19].

Ratio of the Volatile Fatty Acids / Complete Alkalimetric Title

Fig. 4 shows that in the HW, SW and DS digesters, the (VFA/CAT) ratio varied between 2.45 and 0.6 throughout the entire experiment period, which can certainly be attributed to the presence of big quantities of aggregated volatile fatty acids (VFAs).

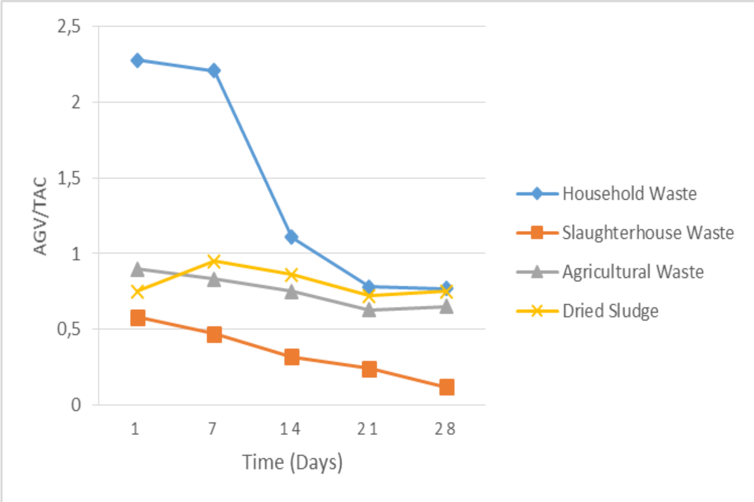


Fig. 4. Evolution of the ratio VFA/CAT

It should be mentioned that the cumulation of VFAs has a negative impact on the progress of the methanization. In addition, similar remarks about the SW and DS digesters turned out to be legitimate. It was found that the (VFA/CAT) ratio started decreasing after the first week but did not go below the value of 0.6. Nonetheless, it was noted that, particularly in the digester of slaughterhouse waste (SW), the pH values varied between 0.5 and 0.1, starting from the third day until the end of the experiment. This finding can be justified by the smooth advance of the methanization procedure. [20, 21

Cumulative biogas and methane yield

In order to know the amount of the produced biogas and methane in each digester, we cumulate the produced volumes, according to Fig. 5; the volume of biogas with household waste (HW) is 95mL at its maximum on the seventh day and then started to rapidly decrease after two weeks of methanization. The same remark was made about the agricultural waste (AW). Further, in the slaughterhouse waste (SW) digester, we recorded low volumes of biogas between 15 and 40mL as a daily maximum throughout the entire experiment period. This explains the low methane production rate in this digester [22].

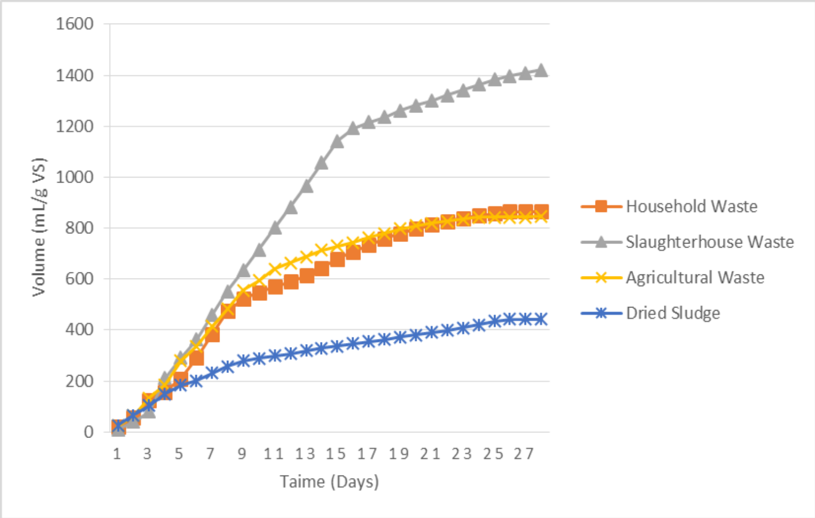


Fig. 5. Cumulative volume of biogas.

Furthermore, in the Agricultural Waste (AW) digester, the volume reached 135 mL of biogas (maximum volume), after four days of methanization. This volume then started to decrease after 17 days of the methanization process. This result is certainly due to the depletion of the organic matter (OM) and to the absence of nutrients as well [23].

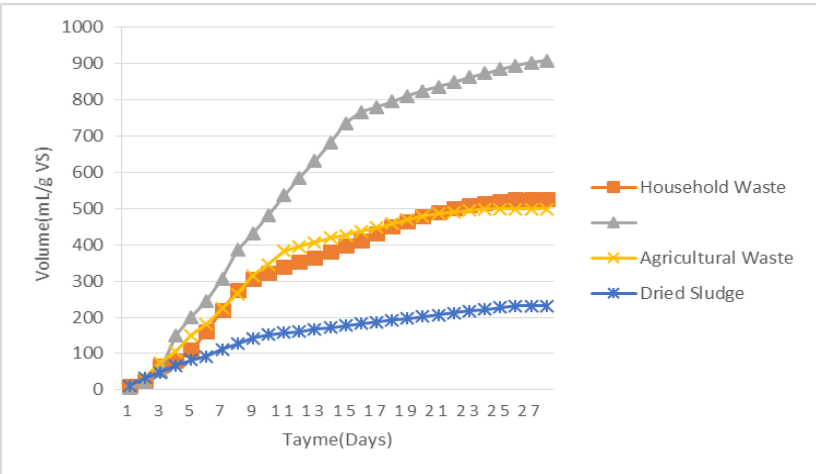


Fig. 6. Cumulative volume of methane.

Fig. 6 shows that the methane volume in the slaughterhouse waste (SW) digester was maximum (98mL) on the 04th day of the process. Next, it varied between 80 and 55mL until the 16th day. This SW digester is the one that that presents the highest methane production rate. Then, the production of this biogas started decreasing to reach volumes between 20 and 40ml on a daily basis in the household waste (HW) and agricultural waste (AW) digesters. As for the dried sludge (DS) digester, there was zero methane production during the first and last weeks of the experiment, with a volume lower than 15 ml for the remaining days, which means that the methanization process failed completely [24].

The largest cumulative volume of biogas and methane is recorded in the Household Waste (HW) digester, 1439mL and 909mL successively (smooth methanization progress), the smallest volumes recorded in the DS digester is 151mLof biogas and 80ml of methane (obstacle of methanization). [25]

Chemical Oxygen Demand and Biological Oxygen Demand

On the other hand, the consumption of oxygen was found to be quite important in the slaughterhouse waste (SW) digester. This is demonstrated by the difference between the COD values of the substrate and the digestate, which is a highly advantageous environment to produce methanogenic bacteria [26]. However, the consumption of oxygen is less important in the other digesters, and particularly in the (DS) digester that contains sludge. The data are recorded in Table 03.

Furthermore, an important value of 14700 mg/l was recorded for the biological oxygen demand (BOD_5) in the slaughterhouse waste (SW) digester. This high value can be attributed to the presence of a significant amount of biodegradable material in the medium. However, the biological oxygen demand values were found much smaller and less important in the other digesters, and particularly in the dried sludge digester [27].

Table 03

Chemical Oxygen Demand and Biological Oxygen Demand before and after digestion

Characteristics		HW	SW	AW	DS
Chemical oxygen demand (mg/L)	Substrate	21333,33	32000	16000	42666,66
	Digestate	18645	11666	7666	29333
Biological oxygen demand (mg/L)	Substrate	13566	15334	14667	12666,66
	Digestate	11643	12666	13666	12333

Reduction rate of the organic matter

With regard to Fig. 8, it explicitly shows a degradation of the organic matter at the end of the digestion process. This degradation took place in all digesters, but it occurred in different ways.

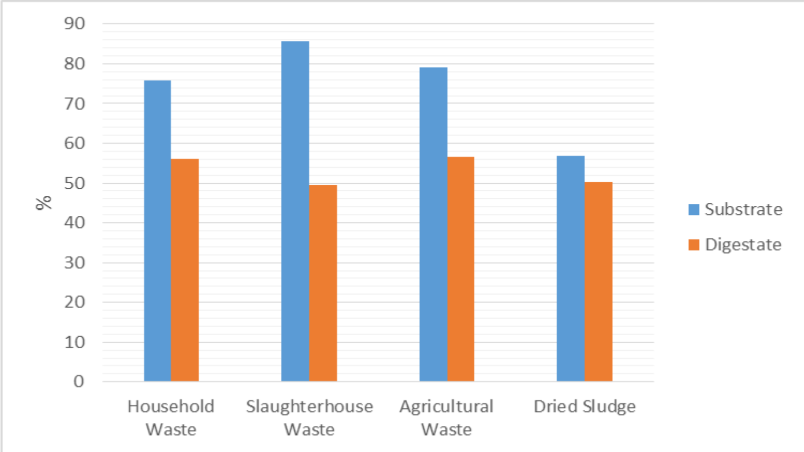


Fig. 8. The organic loading rate before and after digestion

There was a big difference between the organic loading rates of the substrate and digestate in the slaughterhouse waste (SW) digester; this difference was estimated at 45.93%, which indicates a smooth methanization process. However, this difference was less important in the DS digester; it was found equal to 2.85%, which means that the methanization progress failed [28].

4. Conclusion

The present study focused on four types of organic waste, namely household waste, slaughterhouse waste, agricultural waste, and dried sludge from the region of Adrar, that is located in the southwestern part of Algeria. It was revealed that the slaughterhouse waste digester produced the highest volume of biogas (1400 mL), the highest volume of methane (920 mL), with a good consumption of chemical oxygen demand (32862 - 11235mg/L), and a good consumption of organic matter of about (45. 93%) in comparison with the other waste digesters studied. The digesters generated a small volume of biogas (425mL), and a smaller volume of methane (240 mL), with a low consumption of chemical oxygen demand (29333.33 - 26667mg/L), and a small consumption of organic matter (5%).

Consequently, it is highly recommended to use the slaughterhouse waste as a potential feedstock for the anaerobic digestion to produce methane-rich biogas, and also to ensure that the anaerobic digestion process runs smoothly. In this case, the substrate can be used for optimum energy generation.

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