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ORIGINAL ARTICLE

Production of Methane from Banana Peels by Mesophilic Anaerobic Digestion

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KEYWORDS

Alkalinity;
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Digester;
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Methanogenic potential;
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ABSTRACT: Banana peel is a concentrated source of putrid organic waste; this waste is considered as a source of the energy produced by the process of anaerobic digestion. The objective of this study is the evaluation of methane production by anaerobic digestion of banana peels. The experiment was carried out under mesophilic conditions using a semi-continuous laboratory digester (1.5 L) with a constant agitation that maintains the bacterial activity in the digester and reduces the risk of sedimentation. The treated substrate is obtained from the region of ELGHARB, and it was cut and crushed to particles whose size is less than 1 cm. Throughout the period of the experiment, the pH was around neutrality, between 7.4 and 7.9. The average value of alkalinity was 1500 mg L^{-1} which permits the well function of the process. In addition to the control of stability parameters of the anaerobic digestion, there was also a control of the organic loading rate presented by the total solids (TS) and volatile solids (VS). A daily control of methane production shows that the methanogenic potential is 257 m^3 t^{-1}.

INTRODUCTION

Energy policy in Morocco has undergone a major development, since 2014, Morocco has proceeded with energy reforms to enhance energy supply diversification and make energy efficiency a national priority [1]. The banana is the fourth most produced food product in the world. Bananas are grown in over than 100 countries, mainly in developing countries where they are an important staple food [2], and Per ton of bananas harvested about 0.1t of rejected flesh and about 4t of waste were produced [3]; in Morocco, the annual banana production is 140.000 t and the banana waste is about 300.000 t [4].

Banana growing generates an enormous amount of waste (leaves, stems and peels), and the decomposed waste gives rise to the toxic gases such as hydrogen sulfide and ammonia, which threaten the environment. The agro-wastes, including banana peel have been increased due to the improved cultivation techniques and sophisticated processing condition furnished by allied industries that generate thousands of tones of this solid agro-waste which is generally discarded [5, 6].

The past few years have witnessed a various industrial applications of banana peel such as bio-fuel production, bisorbents, pulp and paper, cosmetics, energy related activities, organic fertilizer, environmental cleanup and biotechnology related processes [7, 8]. Indeed, the bananas waste represents a concentrated source of putrid organic waste, very useful in the anaerobic digestion and production of energy while the fermentation products can be used as highly nutritious fertilizer, as well as a valuable source of energy in form of biogas [2]. High biogas yields from banana leaves have been pointed out in several studies [9]. Banana residues are among the best foods for anaerobic digestion, due to its high organic

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composition. The anaerobic digestion or methanisation holds through the succession of several bacterial actions such as hydrolysis acidogenesis, acetogenesis and methanogenesis [10].

The present study evaluates the cumulated methane and biogas production in semi continuous anaerobic digestion where the primary objective is to estimate the ultimate methane. It was carried out in the laboratory and it includes an experimental work and the anaerobic digestion of banana peels. The studied substrate was treated mechanically by a simple grinding, and the size of the particles is smaller than one centimeter. Furthermore, the experience is performed in semi continuous mode in a laboratory digester (1.5 L) under the mesophilic conditions. The anaerobic digestion is made in three phases: activation phase, adaptation phase and substrate treatment phase.

MATERIALS AND METHODS

Description of the digester

It is a laboratory digester with a total volume of 1.5 liters (Figure 1). The useful volume of the reactor was maintained at 1 liter. The reactor is equipped with suitable devices for the feeding, gas collection and drainage of waste, it's equipped also with water heating device around the digester and provided with a double jacket for the circulation of the hot water, and it is totally stirred by means of an electromagnetic stirrer connected to a motor. The reactor was operated in mesophilic conditions (35°C) using a thermostat.

The experiment was performed in semi-continuous mode and the digester is fed daily with substrate while a closed bubblers containing NaOH solution were used to remove the CO_2 that was produced during the process of the anaerobic digestion. The methane production is monitored daily by the water displacement method, and the volume of water displaced from the reservoir connected to the digester is equivalent to the volume of the produced methane.

The total solid is obtained after drying the sample in an oven at 105°C for 24 hours and weighing the residue while the mineral solid is obtained after drying the sample in a muffle furnace at 550°C for 2 hours, then the volatile solid is nothing else but the difference between the total solid and the mineral solid [11].

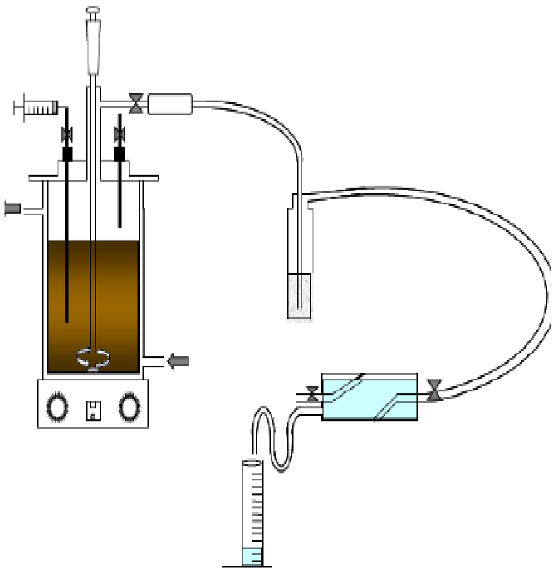

Figure 1. Anaerobic Digester.

Substrate and Inoculum

In this experimental study, the treated substrate is banana peels of the region ELGHARB, these peels were cut into small pieces and ground in an electric blender and the particle size is less than 1 cm. The selection of the inoculum draws upon on its high methanogenic activity [12]. This biomass contains a methanogenic flora capable of degrading the effluent. The used inoculum was obtained from an active digester of a sewage treatment plant in Marrakech (RADEMA) and it allows bringing into the digester the microorganisms capable of degrading substrate which feeds the digester. Table 1 shows the average values of the main parameters characterizing the substrate.

Table 1. Physic-chemical characteristics of banana peel

Parameter	Value
pH	7.9
Moisture (%)	92.8
TS (%)	7.2
VS (% ST)	79.25
MS (% ST)	12.2

Experimental procedure

Generally, the anaerobic digestion is carried out in three phases after the inoculation of the digester. In the first phase, the digester feeding is mainly based on the use of GAL as a simple supply of nutrients; this is the biomass activation phase. The second phase is called adaptation phase; in this step the bacteria are adapted gradually to the new substrate. Finally, the last phase is concerned with the treatment of the substrate where the digester is fed with substrate up to 100%.

The inoculation of digesters is very important in the acceleration of the startup of the process because it ensures a sustainable biogas production by introducing the methanogenic bacteria. In fact, the addition of an inoculum provides an active microbial mass, so it is essential to find an appropriate inoculum containing the methane-producing microorganisms. In this study, the inoculation involves the addition of the inoculum (450 ml) from a digester of 12 000 m^3 that treats sludge from a sewage treatment plant in Marrakech city. Then, the volume of the used inoculum is equivalent to 8 gVS / L; we have also added 1g of yeast, the micronutrients and 2.85 ml of GAL, which is a synthetic solution, in order to bring a simple supplement of nutrients that are essential in the development of microorganisms. Afterwards, 450 ml of distilled water was added to reach the volume of the digester.

RESULTS AND DISCUSSION

Evolution of pH and alkalinity

The results obtained in each phase of the anaerobic digestion in this study are presented and discussed. These results include the measurement of methane production, the control of the organic loading rate and monitoring parameters that indicate the well function of the anaerobic digestion: Ph and alkalinity. Figure 2 shows the variations of the alkalinity in the digester, its average value is 1500 $mg.L^{-1}$, which is an optimal value. It's deemed necessary to have at least 1000 $mg.L^{-1}$of alkalinity (expressed in mg of $CaCO_3$ per liter) in a reactor that works in good condition [13]. In this experiment, as shown in Figure 3, the pH level is between 7.4 and 7.9 with a mean value of 7.5 during all stages of anaerobic digestion, this value is around neutrality that ensures the well function of the process.

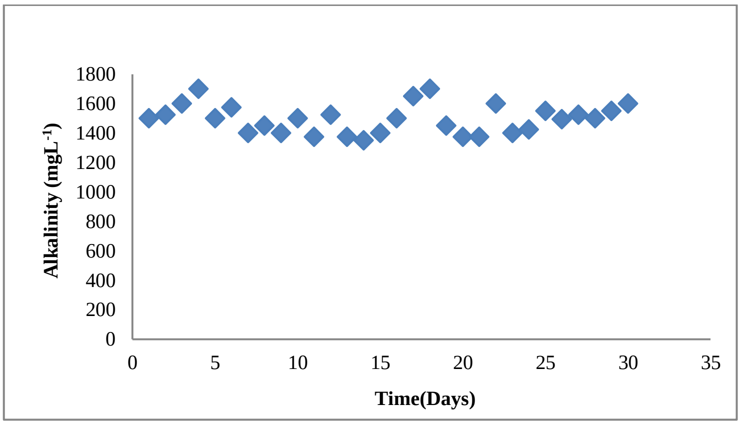

Figure 2. The Alkalinity variation during the mesophilic anaerobic digestion.

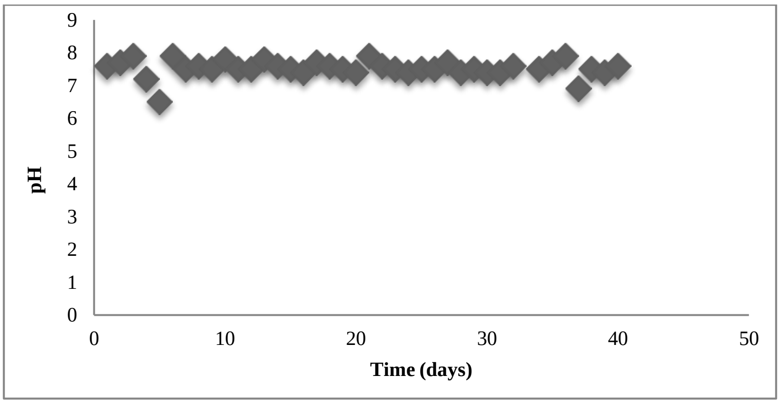

Figure 3. Evolution of pH in the digester.

Methane production

Activation phase

This is the first phase of the experiment, which comes immediately after the inoculation of the digester and aims to activate the living methane-producing microorganisms. Thus, the digester is fed with the GAL, a solution composed of glucose, sodium acetate and lactic acid with concentrations of 0.5, 0.75 and 1 mg L^{-1} respectively, and these elements are easily digested by the methanogenic bacteria which lead to an instantaneous production of methane. The Figure 4 represents the evolution of the production of methane during the activation phase of biomass. The increase of the given charge from 0.25 gVS / ml to 1 gVS / ml leads to the increase of methane production, thereby promoting the metabolic activity of the developed microbial population.

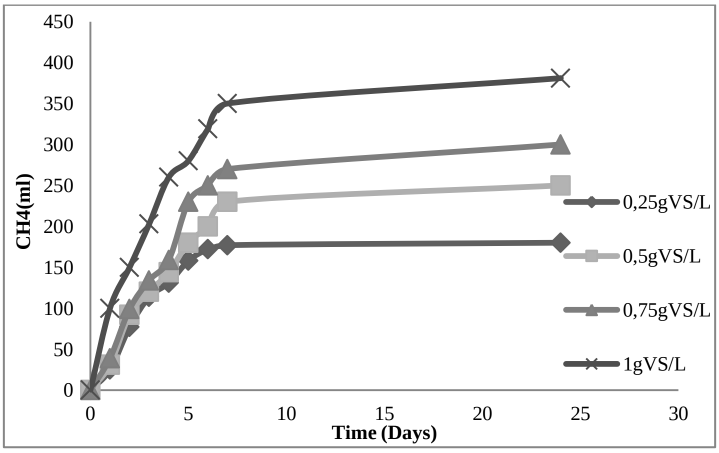

Figure 4. Evolution of CH_4 production in biomass activation phase.

Phase of adaptation

Before proceeding to the treatment of the substrate composed of comminuted banana peels, the bacteria must be adapted to the presence of this substrate in the digester. In fact, these microorganisms are fed with a mixture consisting of 25% of substrate and 75% of GAL (three loads) with a concentration of 0.5 g VS / ml, then 50% of substrate and 50% of GAL, and up to 100% of substrate. Figure 5 shows the evolution of the production of CH_4 in this adaptation phase. We observe that the production of methane decreases as the fraction of the substrate relative to the GAL increases. This evolution is due to the change of the behavior of the bacteria vis-a-vis the new substrate, so, they are able to adapt to new conditions. Thus, the methanogenic microorganisms adapt physiologically to the massive supply of organic matter according to the rigidity of the substrate, this adaptation can be explained by the formation of adaptive enzymes attacking the compounds of the new substrate.

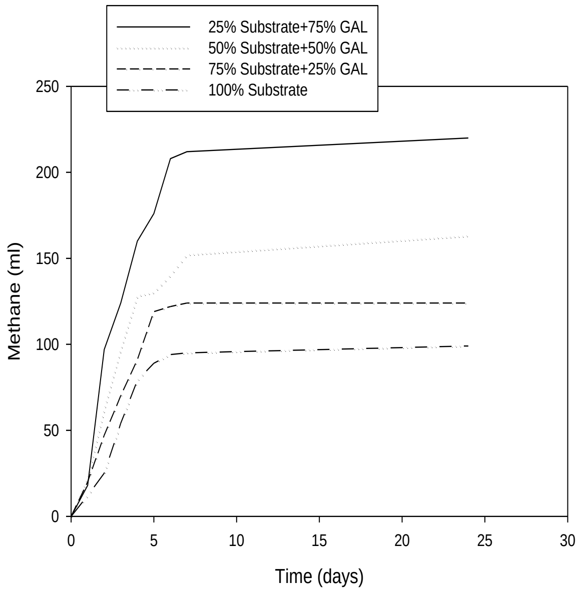

Figure 5. Evolution of CH_4 production in the adaptation phase

Phase of substrate treatment

During this phase, the digester is fed with 100% of substrate without the need to add the GAL and the bacteria are fed by an amount of 0,5 gVS /L of the substrate, this amount increases to 3 gVS /L. Figure 6 shows the evolution of the methane production during the substrate treatment phase. The results indicate a successive increase in the volume of the produced methane with the increases of the given load. This can be explained by the action of methanogenic microorganisms which are already well adapted to the new substrate, and hence they became able to produce enzymes that allow the hydrolysis of the various substrate components and catalyze the metabolic reactions which lead to the production of CH_4.

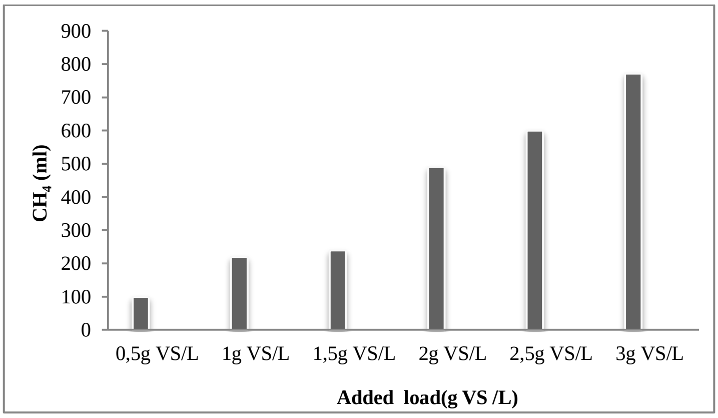

Figure 6. The methane production during the anaerobic digestion of BP for different loads (from 0.5 to 3.00 g VS/L).

Methanogenic potential and evolution of organic matter during the experiment.

The methanogenic potential is the maximum volume of biogas or produced methane per liter of effluent or per kg of waste treated by the method of anaerobic digestion. Since several studies have examined the digestion of banana peel under mesophilic temperature conditions, the methanogenic potential from the banana peel can be compared with that obtained in some of them. In this experiment, the average value of methanogenic potential is 257 m^3 t^{-1} VS, which is close to that found by Gunaseelan, 266 m^3 /t TS, in a study of Banana peel (powdered) with a VS = 86.9-94.3% [8]. Bardiya and al, have found 190 m^3 t^{-1} TS of methanogenic potential in a study on Banana peel (chopped) with a VS = 87% [14]. A value of 322m^3 t^{-1} VS has been obtained in a study of banana and plantain peel (VS =89%) [15].

Table 2 shows the variation of TS and VS in the digester during the experiment. During the adaptation phase, the concentration of the total organic loading rate and volatile organic loading rate which are present in the digester is almost constant before and after each load is placed. This is due to the fact that the substrate provided in the digester is completely degraded under the action of the existing microorganisms. However, the variation of the total solids and volatile solids is very significative in the substrate treatment phase, these two parameters increase as the amount of the substrate placed in the digester increases (from 0.5 to 3 g L^{-1} VS). This indicates that the substrate brought into the digester is not completely biodegraded, and hence leading to their accumulation and this variation of the organic loading rate can be also explained by the synthesis of new substances by bacteria.

Table 2. Variation of total solid and volatile solid during the experiment

	Adaptation phase								**phase of Substrate treatment**									
	25% substrate		**50%**		**75%**		**100%**		**1g**		**1.5g**		**2g**		**2.5g**		**3g**	
	Before	**After**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**
TS (g/L)	13.2	14.1	14.1	12.3	12.3	12.6	12.6	11.2	11.2	10.1	10.1	10.4	10.4	17.1	17.1	19.8	19.8	19.9
VS (g/L)	10.9	9.4	9.4	9.7	9.7	9.66	9.6	6.5	6.5	5.7	5.7	5.9	5.9	9.9	9.9	12.1	12.1	13.3

CONCLUSIONS

The treatment of organic matter by anaerobic digestion can be considered as an immediate solution of the problem of pollution. This work allows contributing to the evaluation of methanogenic potential of banana peels and studying the feasibility and optimization of their valorization by controlling the stability parameters of anaerobic digestion. This study has shown that we can perform, without problems, the anaerobic digestion of banana peels which produces a high yield of methane. The disadvantage of anaerobic digestion of banana peels is the high moisture content. To deal with this problem, it will be better to dry the feedstock and create a nutrient surplus, then the value of the methanogenic potential will be 224 m^3 t^{-1} VS, and with this performance, 1 ton of banana waste in a day can generate approximately 7.5 kW of electricity. Indeed, the methane is a renewable energy source that can be used as a fuel for vehicle, for heating or for production electricity, and hence reducing the fossil fuel. We can conclude that anaerobic digestion is one of the effective methods to strengthen renewable energy sources and limit the problem of pollution and global warming.

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Conflict of interest

I have no conflict of interests.

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