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Characterization and evaluation of methanogenic potential of coffee waste

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Abstract
More and more in our cities the management of the household wastes and industrial by products pose problems and concerns with multiple scopes: environmental, Hygienic. The use of anaerobic digestion as a tool for processing waste has many advantages: it makes it possible to produce a renewable energy, biogas; avoid the carbon emissions in the atmosphere and the pollution of the environment and improve agricultural soil through fertilizer production. This work, which returns in the frame of the management of the solid waste, concerns the study of the anaerobic digestion of coffee waste with the biogas production as a main objective. Thereby, this same study will lead to the determination of anaerobic potential of this waste. The experimental results obtained show clearly that the anaerobic digestion under mesophilic conditions provides a reliable solution for the treatment of this kind of waste; this is proved by the increasing volume of methane obtained and the high biodegradability of organic matter. The methanogenic potential found is about 233.66 NmLCH_4/g VS and the biodegradability reached 81% under these conditions.

1. Introduction
With an ever larger and more diversified consumption worldwide, the production of waste is increasing in quantity and quality thus creating enormous risks on the environment and consequently the health of the population [1]**.** The optimal solution to dispose of waste would therefore be their valuations.
The coffee waste and sub-products corresponding during the processing of the coffee berries are a source of contamination that may pose environmental problems in coffee producing countries, because of their high organic fraction.
Anaerobic digestion is a valuation technique of organic wastes, which includes the waste coffee which are the subject of our study. Indeed, the study considers the digestibility of such waste and the mastery of biogas phenomenon and, for the implementation of an experimental protocol already studied in the laboratory [2, 3, 4]. The experiment was conducted in a CSTR digester kind.
Methane production from organic waste through anaerobic digestion process is more and more considered worldwide and is considered as ideal in many respects because of its economic and environmental benefits [5, 6]. Several studies are interested in the valorisation by anaerobic digestion of coffee waste. We include for example Hofmann and Baier [7], who reported a performance of biogas from 380 m^3/t VS (57-66 % methane) from pulp of coffee for the batch mode and a yield of biogas production from 900 m^3 / t VS for semi continuous experiments. On the other hand Kivaisi and Rubindamayugi [8] have shown that the solid waste coffee of Robusta and Arabica, respectively, have the potential of methane from 650 and 730 m^3/t VS. In our study, the value of methanogenic potential is 233.66 NmLCH_4/g VS (m^3/t = mL/g).
The aim is to study the production of methane from coffee wastes, in mesophilic conditions, on the one hand, and to establish reliable data on the characterization of coffee waste that controls the different parameters that affect the process, and the determination of the methanogenic potential on the other hand.

2. Materials and methods
2.1. Experimental devices
Anaerobic digestion of coffee waste was studied in a completely mixed digester CSTR (Continuous Stirred-tank reactors), in Pyrex, cylindrical volume of 1.5 L. It is considered a completely continuous stirred reactor. The

treatment unit includes mainly a cover of a system of sealing and a jacket for the circulation of hot water. It is equipped with a magnetic stirrer and a thermostat that is used to control the temperature of the water at 37 °C for the mesophilic conditions. This reactor was fed through 3 holes; the first allows you to feed the digester by the liquid substrate, the second to feed the digester by the solid substrate and the third to remove the sample of the digester. This strategy allows to perform the necessary analyzes for the monitoring the process. The volume of methane produced during the process has been measured using a reservoir of Boyle-Mariotte type of 2 liters connected to the reactor. To remove the emissions of CO_2 produced during the process, we use a bubbler filled with normality 6 N Caustic soda solution, which connects the reactor to the Gasometer.

2.2. *Inoculum*
Anaerobic digestion requires the use of an inoculum rich in bacteria able to degrade the organic matter. The inoculum used is constituted of sludge from an anaerobic digester treatment of sludge, the sewage treatment plant in the city of Marrakech. It has been selected on the basis of its strong activity methanogen. In practice, it is possible to use a mesophilic inoculum to start a thermophilic digester of anaerobic digestion treating effluent or solid waste [9].

The table **1** shows the physico-chemical characteristics of the inoculum used.

Table 1. Physico-chemical characteristics of the inoculum.

Parameters	Values
pH	**7.8 ± 0.1**
Alkalinity (mgCaCO$_3$/L)	**5750**
TS (%)	**1**
MS (% TS)	**20.82**
VS (% TS)	**79.17**
TS (g/L)	**29.07 ± 2.63**
MS (g/L)	**9.14 ± 2.81**
VS (g/L)	**19.93 ± 0.18**

2.3. *Substrate*
The coffee waste in question has been harvested from a restaurant cafe in Kenitra city. It was dried by evaporation in an oven at 105 °C (in general during 24 h) in order to determine the content of total dry matter (MS) and then has been burned in the oven at 550 °C during 2 h. After cooling, the crucible is weighed again: It remain only the mineral matter, by difference with the dry materials, the mass of volatile matter at 550 °C is determined. Parameters such as pH, total solids (TS), volatile solids (VS), and inorganic solids (MS) were determined in the coffee waste before the start of the digestion process. All analyzes were performed in conformity with standard methods APHA. The average values of the main parameters characterizing this substrate are shown in the table 2.

2.4. *Experimental stages*
To start the process of anaerobic digestion, the reactor was initially inoculated by 7 g VS/L of anaerobic sludge recovered from inside a digester of sewage wastewater plant. The purpose of this operation is to bring the population of bacteria essential for any anaerobic digestion. After filling the digester of the inoculum, the latter is then fed, a daily basis, by a synthetic solution (GAL solution) [10]. Early in the process, these solutions are very important for the promotion of bacterial growth and metabolism, and to compensate for the lack of nutrients in the substrate [11]. And then it is fed by a mixture of the solution (GAL) and substrate, for the adaptation of the microflora to its new food. Finally the digester is only fed by the substrate to be treated.
The digester was maintained at mesophilic conditions at 37 °C.

2.5. *Technical methods*
Monitoring the process of anaerobic digestion of organic coffee waste was accompanied by analyzes of several parameters such as:
- The pH
- The alkalinity
- The total solids (TS)
- The mineral solids (MS)
- The volatile solids (VS)

Table 2. Physical and chemical characteristics of coffee waste.

Parameters	Values
TS (%)	19.24
MS (% TS)	2.49
VS (% TS)	97.50
TS (g/kg)	209.26 ± 23.80
MS (g/kg)	4.82 ± 0.04
VS (g/kg)	204.44 ± 23.76

3. Results and discussion

The experimental results obtained allowed to follow the variations in the parameters relating to the anaerobic digestion of coffee waste during the corresponding tests. Stability, biodegradability, the methanogenic potential was determined by monitoring parameters of the experiment.

3.1. *Stability of the reactor*

3.1.1. *pH Evolution*

The methanogenic group of organisms is the most sensitive to pH. An acidic pH can cause the stopping of the chain of biological reactions during digestion [12]. The following table 3 shows the pH measured after each load addition.

Table 3. pH values measured after the addition of each coffee load.

Load added (gVS/L)	pH
0.5	7.59 ± 0.43
1	7.83 ± 0.09
1.5	7.58 ± 0.25
2	7.5 ± 0.14
2.5	7.55 ± 0.07
3	7.45 ± 0.07

As shown in the figure **1**, the pH of the digester operating is between 7.45 and 7.83 during the entire follow-up period with an average value of 7.58. This value promotes the stability of the process and therefore the good functioning of the digester.

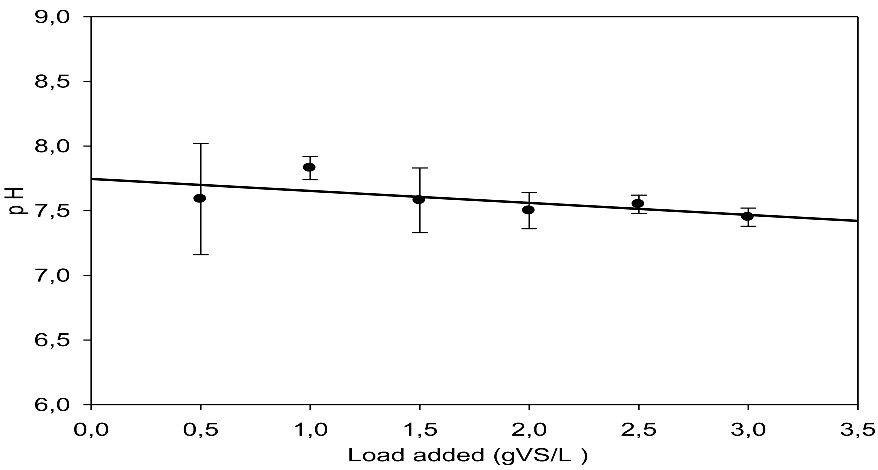

Figure 1. pH evolution as a function of the load added

3.1.2. *Evolution of alkalinity*

The alkalinity due to calcium bicarbonate should be relatively high for the proper functioning of the digester. It is considered, in general, that it is necessary to have at least 1000 mg L^{-1} of alkalinity (expressed as $CaCO_3$) in a reactor which works properly [13].

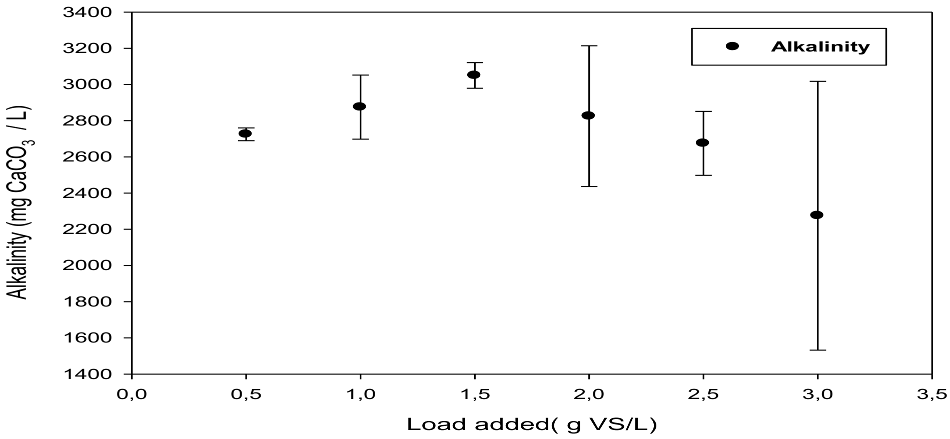

Figure 2. Evolution of the alkalinity as a function of the load added

The results reported on the figure **2**, show that the values of the alkalinity are all superior to 1000 mg $CaCO_3$/L, which indicates that the process works well without risk of acidification.

3.1.3. *Evolution of total solids (TS), of volatile solids (VS) and solid minerals (MS)*

The following table shows the evolution of the quantity of matter (TS, VS and MS) after each load added.

Table 4. The measured values of various solid for each load added.

Load added (g VS/L)	TS (g/L)	VS (g/L)	MS (g/L)
0.5	**10.44 ± 0.07**	**5.95±0.35**	**4.60±0.44**
1	**11.10 ± 0.86**	**6.92 ±1.01**	**4.18 ±0.15**
1.5	**19.14 ±10.50**	**10.15 ±3.54**	**8.99±6.95**
2	**20.81 ±8.13**	**12.91 ±0.35**	**7.9 ±8.49**
2.5	**19.45 ±6.21**	**16.81 ±5.16**	**2.63 ±1.05**
3	**27.74 ±5.50**	**24.5 ±5.69**	**3.24 ±0.19**

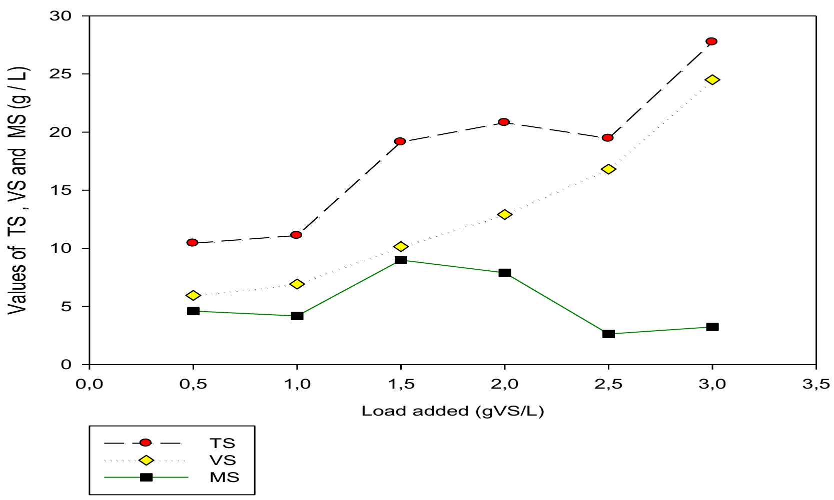

Figure 3. Evolution of TS, VS and MS as a function of the load added

During the experiment, the results obtained are expressed as a function of volatile solids (VS). Figure **3** shows an increase of volatile solids in the digester, this increase is due to the accumulation of organic matter not degraded, and the adaptation of the microbial population to the new substrate. Thus it represents the change in the value of total solids in the digester, in function of the added load. This variation gives an idea on the degradation or the accumulation of biomass in the digester during the process of the anaerobic digestion.

3.2. *Biodegradability*

The biodegradability test or biodegradation test allows calculating the rate of biodegradability of organic substances. The rate of biodegradation of coffee waste is calculated on the basis of the ratio of volatile solid eliminated and the volatile solid added either:

$$\text{Biodegradability} = \frac{\text{SV eliminated} * 100}{\text{SV added}}$$

In our case, we find that the biodegradability of coffee waste could reach the value of 81 %. It can then be argued that the biodegradability of the substrate is acceptable for the biogas production process. Figure **4** shows the relationship between the concentrations of added volatile solids and eliminated volatile solids. The slope of the line indicates the percentage of biodegradability of coffee waste, which in this case could reach 0.81 g $VS_{eliminated}$ /g VS_{added}, this means that 81 % of the added substrate (expressed in volatile solids) is eliminated or degraded during mesophilic anaerobic digestion for this type of waste to produce methane.

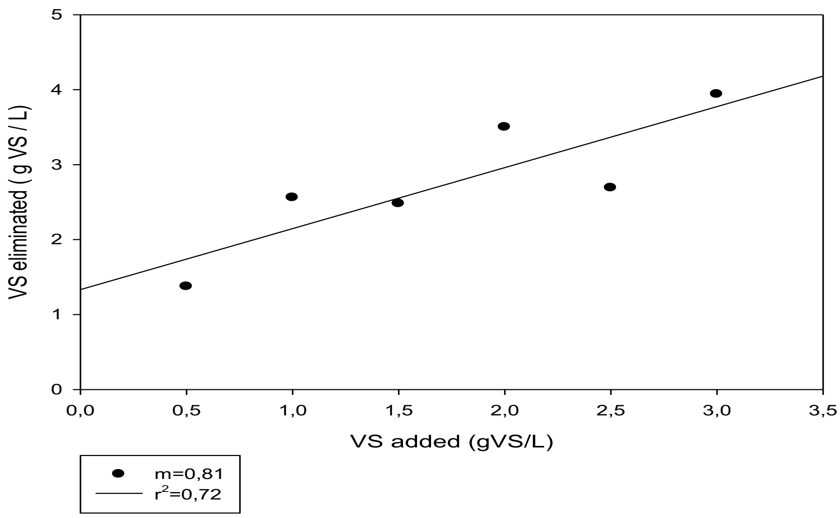

Figure 4. Relationship between the load added (g VS/L) and the eliminated load (g VS/L) during the experiment

3.3. *Methane production*

Methane production is probably the most important parameter in monitoring the control of anaerobic digestion, since it integrates all the other process parameters. This biogas production is a function of organic charge rate, the overall stability of the activity of micro-organisms inside the digester, and the temperature in the digester [14]. The volume of methane produced by coffee waste has been measured in a daily basis, in order to determine the potential of the methanogenic substrate. It is found that the volume of methane increases with the increase of the mass of the added substrate. Thus, the methanogenic potential is determined from the cumulative amount of methane produced during the test. The load 3gVS /L had the maximum potential methanogenic (233. 66NmLCH_4 / g VS) during this experience. The table 5 shows the methanogenic potential and the cumulative volume of methane for added charge.

Table 5. Values of the volume of produced methane and the methanogenic potential for different loads added.

Load (g VS)	Volume of the produced methane (NmL)	Methanogenic Potential (NmL/g VS)
0.5	**63**	**126**
1	**184**	**184**
1.5	**325**	**216.66**
2	**296.5**	**148.25**
2.5	**448.5**	**179.4**
3	**701**	**233.66**

We observe, based on the results below that the cumulative volumes of methane and methanogenic potential grow as a function of the load added that is in perfect agreement with recent studies in the laboratory [15]. Nevertheless, it would be useful to study the behaviour of these two parameters in the hereafter a load of three grams.

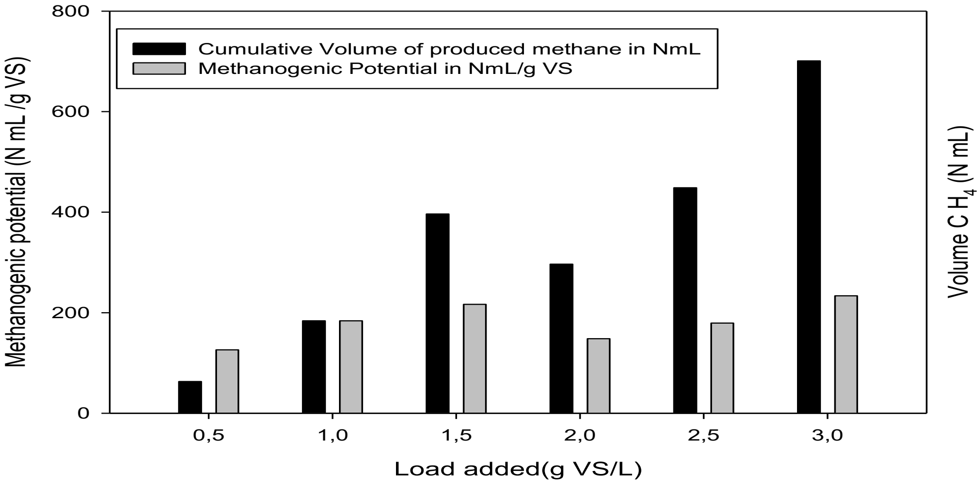

Figure 5. Comparison between the cumulative amounts of methane production and methanogenic potential for all loads added (this study)

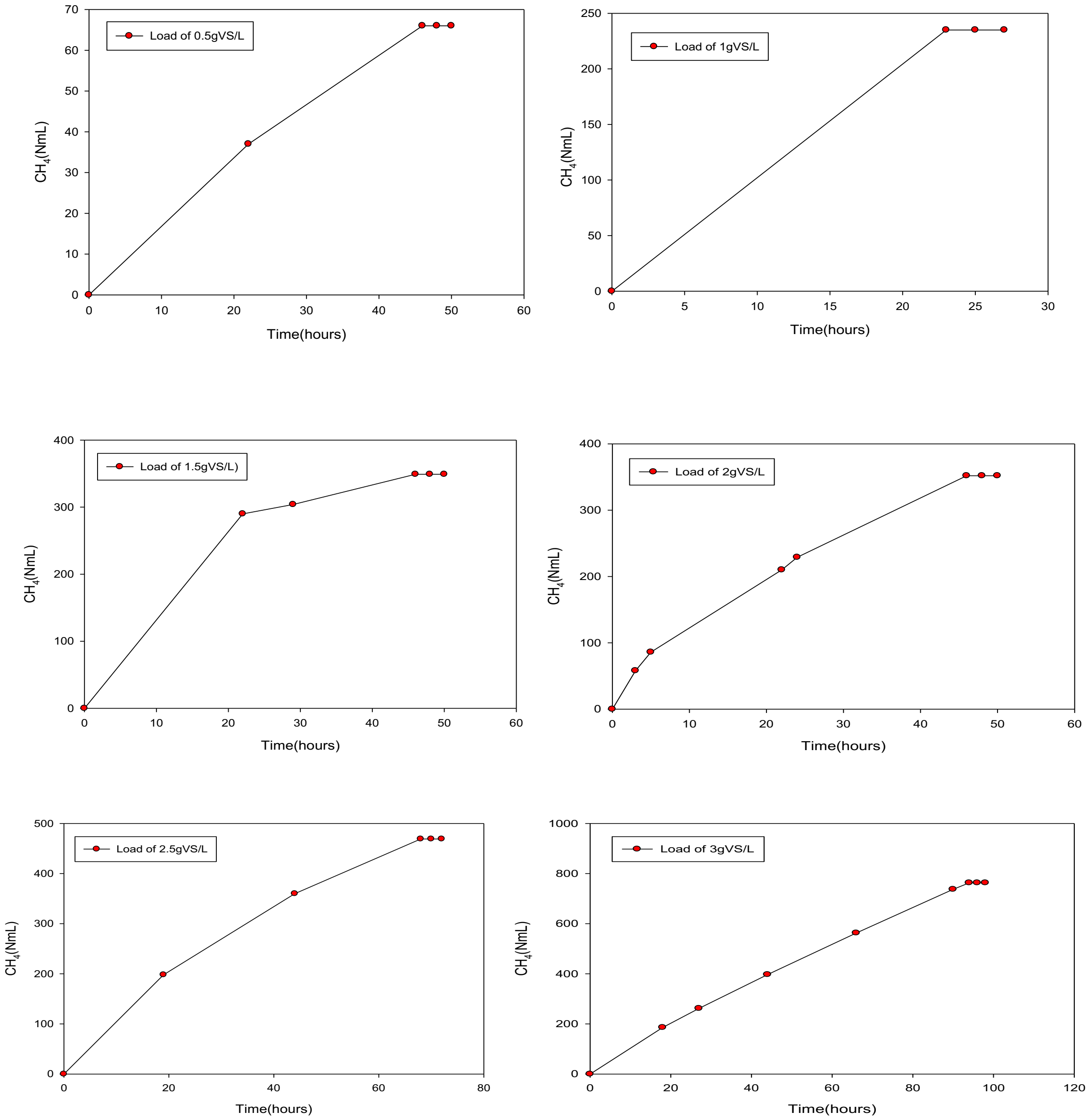

Figure 6. The experimental production of methane as a function of time during the process for different loads added

Conclusion

The results of this study show that the coffee waste presents a large proportion of volatile solids (VS) in the order of 97.50 %. The production of methane as a result of the anaerobic digestion of this waste leads to results more than satisfactory and encouraging. The potential maximum methanogen found in this study has reached 233.66 ($NmLCH_4$ /g VS) for an added charge in 3 g .

Furthermore, we note that the stability of the pH positively affects the development of the bacterial flora responsible for anaerobic digestion.

We can conclude, following the obtained results recorded, that the anaerobic digestion of the waste from the coffee in particular could be undoubtedly a sustainable alternative of recovery of this organic waste.

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