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Assessment of the Methanogen Potential of Water Hyacinth: Effect of Moisture on the Process

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Abstract

In Benin, in wetlands, lakes and rivers are in their majority invaded by water hyacinth which is a threat to the balance of these ecosystems. Indeed, the populations of these areas do not live with an appropriate sanitation. These watercourses have become the receptacles for waste disposal. This study aims, through anaerobic digestion to provide solutions to the risks of this plant, whose proliferation is due to the excessive intake of nutrients (N, P) in these environments. During this study the methanogen potential of this plant and the influence due to the different substrates have been assessed. Thus, the passage in the oven gives a hyacinth dry mass of 4.72% or a moisture content of 95.28%. Experiments conducted in the laboratory when testing BMP have revealed that moisture could be a limiting factor in the process if the optimum volume of water to add for the hydrolysis stage were not determined accurately. In addition to this test, the implemented platform of anaerobic digestion has contributed, from the volumes of biogas obtained to validate the model Meraz as close as the actual production of biogas.

Keywords: Waste, hyacinth, methanogen potential, moisture.

Introduction

In Benin, as in many developing countries (DCs) in the sub-region of West Africa, the lacustrian areas face a real environmental problem, eutrophication, due to the waste mismanagement in these environments and whose direct consequence is the excessive proliferation of water hyacinth. This is an invasive aquatic plant native to the Amazon, and spread by humans through horticulture in tropical and subtropical regions[1-3,]. Annoyances caused by this plant require further urgent solutions to eradicate the water hyacinth since the means used to date have unfortunately not been able to overcome this trouble. Anaerobic digestion, waste recovery industry, is now an alternative in the context of this struggle. However in developing countries, people do not really master the ways to valorize waste[4] and in recent years, many persons working in the field of waste management have interested themselves to those ways in order to study their conditions of implementation and enforcement. Anaerobic digestion is one of the technologies used to both generate power and to reduce the organic fraction of waste[5]. Despite its many advantages, this method of recovery of organic waste is not commonly practiced in Benin and unknown to the general public. Anaerobic digestion is a process of bioconversion used to treat various types of organic waste and recover energy in the form of biogas containing mainly methane (CH_4) and carbon dioxide CO_2[6]. The amount of biogas produced, related to the amount of material introduced into the digester will vary depending on several factors such as quality of organic matter and the technical feasibility parameters such as temperature, humidity, pH[7,5,8]. Anaerobic digestion takes place in four stages that are hydrolysis, acid formation, acetogenesis and methanogenesis during which the decomposition of the substrate is produced by specific microorganisms. Hydrolysis, the first step, deserves special attention because of the fact that on this stage depend the other ones. Indeed, the development of anaerobic bacteria responsible for digestion requires moisture levels above 25%[9]. The temperature as for it may lie in thermophilic, mesophilic or psychrophilic intervals. Many authors showed that the temperature do not significantly affect the amount of methane produced[10]. However, it must be kept stable for a smooth operation of anaerobic digestion[11,12].

Thus, in this study, the anaerobic digestion of water hyacinth associated with excreta, which also pose a management problem, was implemented at room temperature (25-28°C). Studies conducted in the laboratory during a BMP test have shown that fermentation of water hyacinth and sludge is indeed possible and this with specific moisture rates. A platform of methane was also set up to confirm the results obtained from studies in the laboratory.

Material and Methods

Characteristics of substratum used: Water hyacinth used in this study was taken from Lake Nokoué particularly in the area of Ganvié and surroundings. Excreta were collected from cesspits. Tests for determining the dry weights of these two substratums were then implemented in order to define the weight of substratum we should use in our study and which volume of biogas would be obtained.

The dry mass was determined using the method described in standard NF U-44-171. It respects the following protocol: i. sample of hyacinth is cut into small pieces, ii. a sample of each substratum is then prepared to be tested, iii. the cup used for this purpose is weighed empty, iv. the cup containing the sample is then weighed, v. all went in the oven (type DL 53 and VWR brand) at 105 ° C for 24 h until constant weight and then, vi. cup and samples are weighed after taken from the oven.

The measurements were made twice. The masses of the different substratum before and after passage in the oven are respectively denoted M_B and M_S; M_B is the gross weight of sample and M_S its dry weight. The moisture content of samples are therefore determined by:

$$\%H = \frac{M_B - M_S}{M_B} \times 100$$

Biodegradability test of water hyacinth and excreta: In this section, the BMP (bio methane potential) test was implemented on water hyacinth and excreta.

Experimental setup of the test: We used 'batch' digesters. Our experiment was therefore conducted in eight (08) serum bottles with a capacity of 500 ml, four of which were used as digesters and the four remaining served for biogas recovery. The incubation bottles were closed hermetically and then linked to those of the biogas storage by connecting pipes (infuser sets). The storage bottles are filled with lemon water to prevent the dissolution of CO_2 and thus returned in a container with the same water. The device is shown in figure 1, 2 and 3.

Figure-1
Cutting of the water hyacinth

Figure-2
Experimental setup of the BMP test

Figure -3
Substratum and digesters setup

Experimental protocol: After determining their dry masses, it was performed the incubation at room temperature, between 25°C and 28°C, of four (04) samples of hyacinth and excreta in order to determine their methanogen potential and verify the effects of moisture on the fermentation parameters of these substratum: sample 1: 20 g hyacinth + 100 ml water, sample 2: 20 g hyacinth + 20 g faeces + 100 ml water, sample 3: 20 g hyacinth + 200 ml water, sample 4: 20 g faeces + 100 ml water.

The theoretical volumes of biogas are obtained from Tchobanoglous and Meraz models. This allowed us, by comparing these volumes with those obtained in a practical way to validate one of these models.

Tchobanoglous model based on waste quickly decomposable[13].

$$C_{68}H_{111}O_{50}N + 16H_2O \rightarrow 35CH_4 + 33CO_2 + NH_3$$

Méraz model[14]

$$C_6H_{12}O_6(s) + 0{,}18\,NH_3 \rightarrow 2{,}53CH_4 + 2{,}54CO_2 + 0{,}42H_2O(l) + 0{,}93CH_{1,7}O_{0,5}N_{0,2}$$

Parallel to the BMP test, a platform was set up in order to assess the actual volumes of biogas obtained during the implementation process of digestion in the fight against water hyacinth.

Anaerobic digestion platform: Experimental setup: This platform was implemented in the technology and practical center for water supply and sanitation of civil engineering department of ecole polytechnique d'Abomey-Calavi (EPAC). The system set up consists of two metal barrels of 204L capacity used as batch digesters, two craft pressure-gauges, a network of pipes used to transport the biogas produced, two water traps, two tubes of biogas filtration and several inner tubes for recovery of biogas (figure 3). The filtration devices were used to purify the biogas and thus get only methane at the end of the network. The network is equipped with valves at the outlet of the digesters and the entry of inner tubes to control the flow of biogas produced and methane recovered (figure 4 and 5).

Experimental Protocol: Both digesters were filled with fresh water hyacinth finely divided (particle size less than or equal to 5cm). The first digester was filled with 22kg of hyacinth and 20L of sludge, while the second was loaded with 18 kg of hyacinth and a volume of 20L of water. The theoretical volumes of biogas obtained here are also given by the models and Tchobanoglous Meraz presented above.

Results and Discussion

Determination of the dry weight of the substrates used: The results presented in table 1 give about water hyacinth, an average percentage of dry mass of 4.72% for an average moisture content of 95.28%, a value close to 93.88 % found by many authors[4]. According to, the amount of water in hyacinth is between 94 and 95% of its weight[15]. Excreta in turn, give an average moisture content of 74% for a dry weight estimated at 26% of the total mass of the substratum. These results for the dry weight were therefore used to estimate the theoretical volumes of biogas obtained during the test.

Table-1
Results of the BMP test: Theoretical volumes of biogas and actual volumes obtained

	Substratum			
	1st experiment		2nd experiment	
	Hyacinth	Faeces	Hyacinth	Faeces
Initial weight	45 g	83 g	100 g	100 g
Dry weight	2 g	21 g	5 g	27 g

The masses used for testing (20 grams) correspond respectively to a dry mass of 0.94 g of hyacinth and 5.2 g of faeces. These dry weights, using models of biogas generation, allow us to estimate the theoretical volumes of biogas. Measurements of the volume of biogas produced are made at intervals of three days over a period of 42 days. Prepared samples for testing are: sample 1: 20g hyacinth + 100 ml water, sample 2: 20g Hyacinth + 20g faeces + 100 ml water, sample 3: 20g hyacinth + 200ml water, sample 4: 20 g of faeces + 100ml water.

Table-2
Volumes given by models of biogas production

	Water Hyacinth	Feaces
Tchobanoglous	829,50 ml	4,57 L
Méraz	592,00 ml	3,30 L

Actual volumes of biogas obtained are shown on the curves in figure - 6.

The volumes of biogas obtained in samples 2 and 4 are respectively 500 ml at 21 days and 494 ml at 24 days. At these levels, the test was interrupted because of the carrying capacity (500 ml) of the bottles used as digesters in order to prevent their explosion. The sample 1 has known a constant evolution of biogas production until the 39th day and it reached a value of 470 ml. The sample 3 consisting of 20 grams of hyacinth and 200 ml of water, meanwhile, recorded a cessation of production of biogas at 21 days where it reached a value of 197 ml.

Effect of moisture on the degradation of the water hyacinth: Comparing samples 1 and 3, the difference lies in the volume of water added to the water hyacinth. Biogas production from the sample 3 peaked at day 10 (42ml) and then decreased gradually until the complete cessation of production at day 21 (figure - 7). This could be due to the large amount of water present in the sample since the hyacinth, itself, already contains about 95% humidity. Indeed, a too high moisture levels is an obstacle to the anaerobic degradation. And that was felt at this sample. It is probably an accumulation of hydrogen due to the amount of water and thus accumulation of acids in the medium that results to that decrease in biogas production and to a blocking process. Too much water can promote strong hydrolysis and then lead to blockage of methanogenic anaerobic reactions. Biogas production in the first sample, however, had a normal development with a peak of 50 ml day 21 (figure - 7)**.** The water then turns out to be a limiting factor in the process of anaerobic digestion not only for water hyacinth but also for the other organic substratum used.

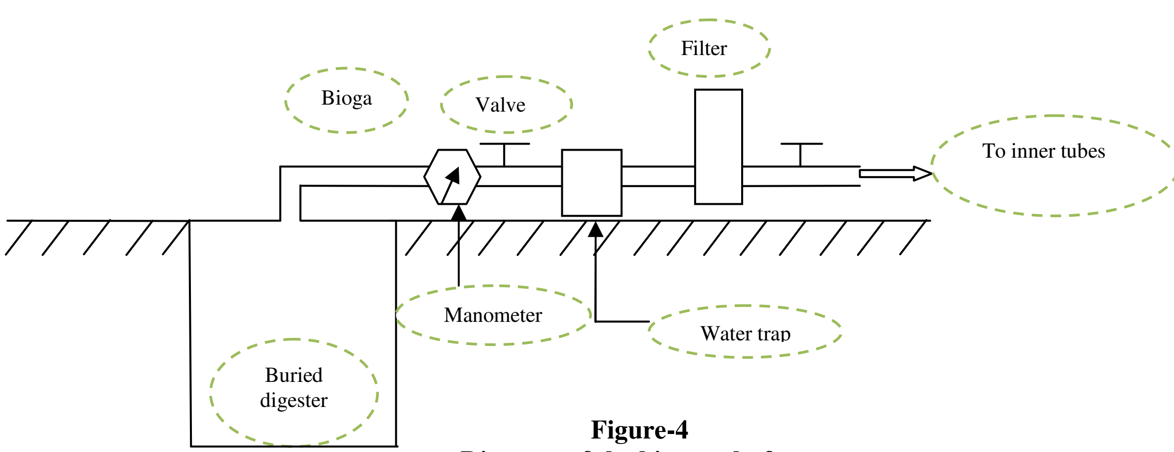

Figure-4
Diagram of the biogas platform

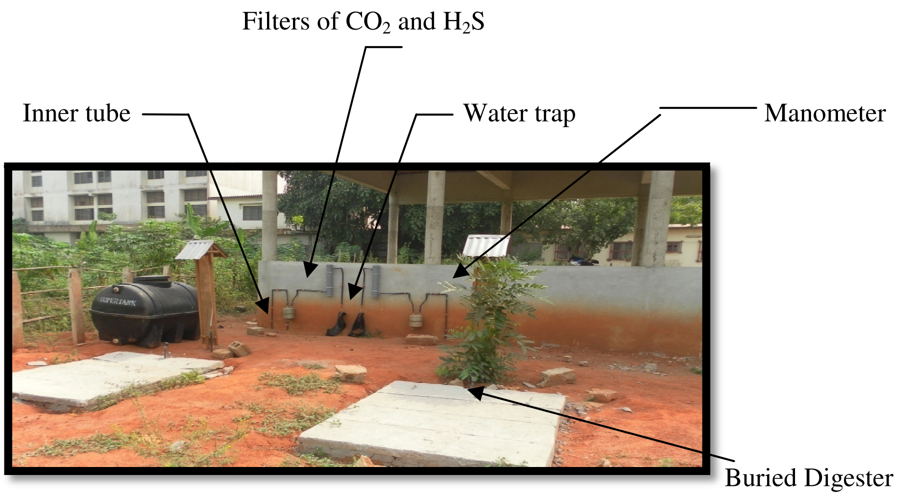

Photo-5
Anaerobic digestion platform and its components

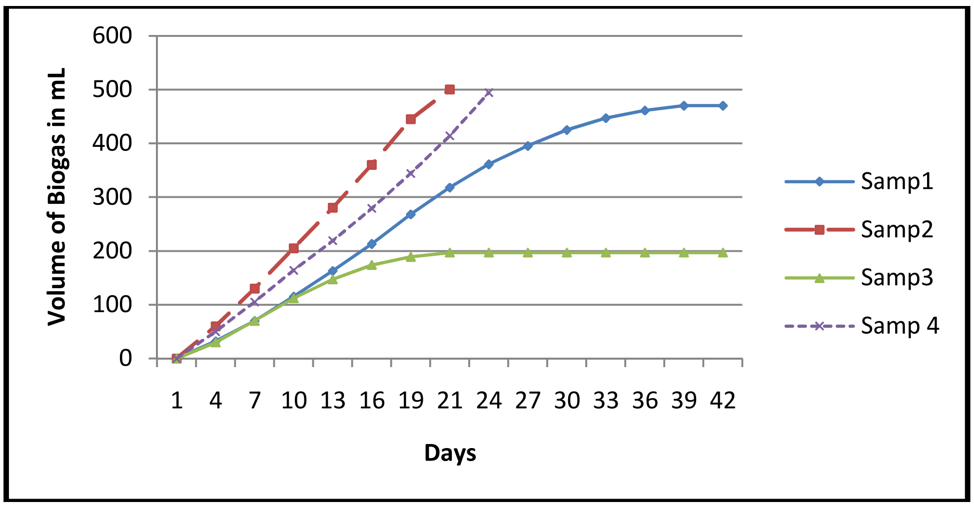

Figure-6
Volumes of biogas obtained

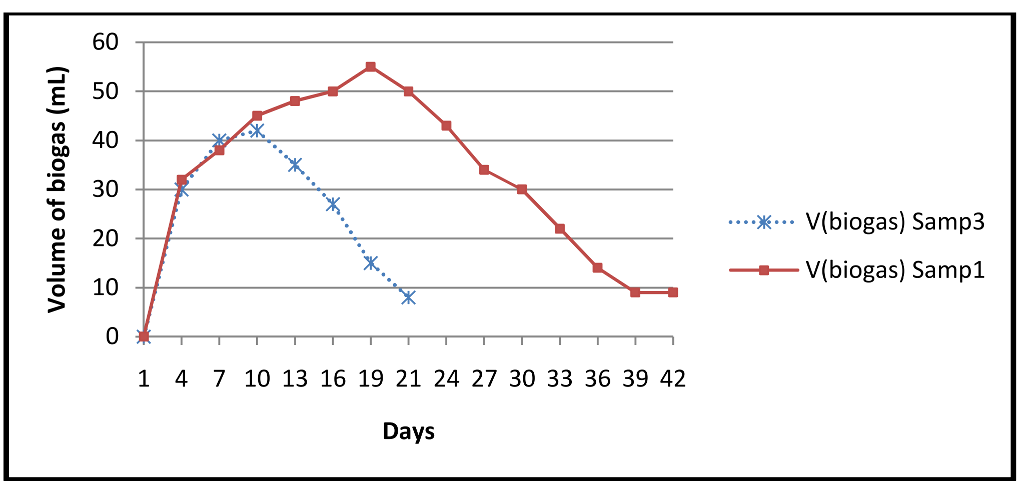

Figure-7
Evolution of biogas production over time

Table-3
Prospective theoretical volumes of biogas

	1st Barrel	2nd Barrel
Tchobanoglous model	955 L	781 L
Méraz model	689 L	564 L

These curves each have a shape divided into two parts: the first step corresponds to an increase in gas production per unit of time that is proportional to the volume of gas already produced: *exponential growth*; the second step corresponds to a decrease in gas production which is proportional to the remaining gas to produce: *exponential reduction*.

This observation confirms the results presented by the kinetic model LOCM (landfill odor characterization model), developed by many authors[16], whose evolution curve of the biogas is similar to the one we obtained. The following formulas express the LOCM model:

1st Step: $t_x < t_{1/2}: \frac{dG}{dt} = K_1 G_0 N_x \exp[-K_1(t_{1/2} - t_x)]$

2nd Step: $t_{1/2} < t_x: \frac{dG}{dt} = K_2 G_0 N_x \exp[-K_2(t_x - t_{1/2})]$

Where: G_o: theoretical production potential, G_o = 1.868.Corg.[0.014 (T-273) + 0.28] m^3/T, K_1: rate constant for first step (yr^{-1}) =Ln50/ $t_{1/2}$, K_2: rate constant for second step (yr^{-1}) = Ln50/($t_{99/100}$- $t_{1/2}$) and $t_{1/2}$ = variable depending on the substrates. The substrate in the case of this study is a rapidly decomposable fraction, and then $t_{1/2}$= 1 year.

Volumes of biogas obtained on the anaerobic digestion platform: Recall that the first barrel (digester) was filled with 22kg of hyacinth and 20 l of sludge drain while the second received 18 kg and 20 liters of water hyacinth.

This pilot-scale experimentation gave for the first digester a volume of 275 L of methane and the second 230 L of methane. By assuming that the volume of methane obtained during anaerobic digestion is half the volume of biogas produced, so we get respectively 550 L and 460 L of biogas produced in the first and the second barrel.

Validation of predictive models of biogas generation: When we look at the graphs below, both the BMP test and the platform of anaerobic digestion give biogas volumes that seem to be much closer to those given by the Méraz model. This glucose-based model would seem best to approach the reality than the Tchobanoglous model which overestimates the amount of biogas obtained from a given substrate.

Furthermore, by observing the actual volumes achieved, both during the BMP test and on the platform of anaerobic digestion, we find that there is a correlation between the actual volumes and those given by the model of Tchobanoglous on one hand and the one of Meraz on the other hand such as: $V_T \approx \alpha V_r$ with V_T is the theoretical volume given by the models and V_r, the actual volume obtained during the experiments.

Thus, we determine for the model of Tchobanoglous, $\alpha_1 \approx 1{,}75$ and $\alpha_2 \approx 1{,}25$ for the one of Meraz. These results allow to approach more precisely the volume of biogas obtained, knowing the amount of substrates introduced into a digester. This will therefore limit leakage in future experiments to optimize the process and to evaluate the influence of the conditions (temperature and pressure) in an environment where the molar volumes are often not of 22.4 l.

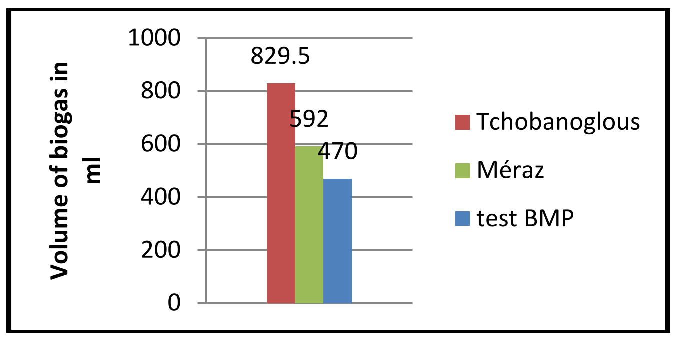

Figure-8
Theoretical and actual volumes given by the BMP test

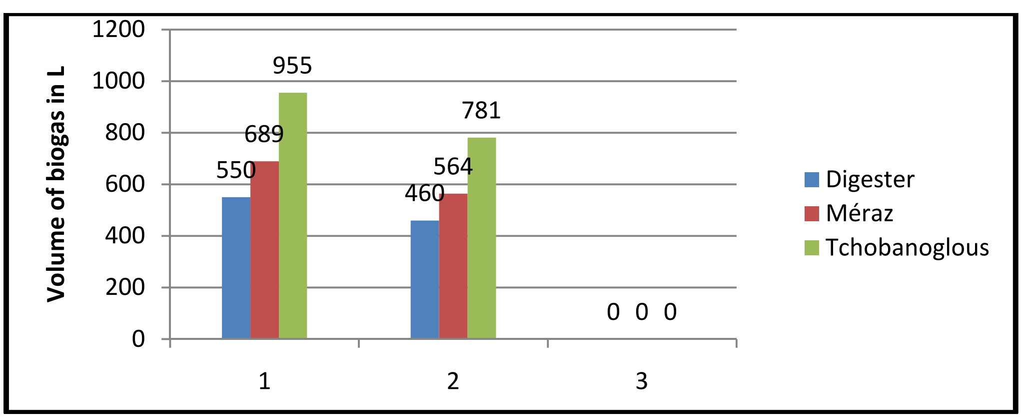

Figure-9
Theoretical and actual volumes given on the platform

Conclusion

Anaerobic digestion is a technology whose application in the lacustrian areas infested with water hyacinth has many advantages such as energy production. The tests for determining the dry weight revealed for the water hyacinth a moisture average of 95.28%. This plant is due to the humidity, the material of choice for anaerobic digestion. However in order to optimize the process, this study revealed that special attention should be paid to the hydrolysis step which consist of adding to the reaction a certain volume of water. This could indeed become the limiting step of the process if the optimum volume of water to be added is not determined precisely. However in order to optimize the process, this study revealed firstly that special attention should be paid to the hydrolysis step which consists of adding to the reaction a certain volume of water. This could indeed become the limiting step of the process if the optimum volume of water to be added is not determined precisely. And secondly, it has been noted that there are proportionality links between the volume given by the theoretical models and the actual volumes achieved in practice, allowing a better approximation of the volumes to get in such trials.

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