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Effect of Solids Concentration on the Kinetic of Biogas Production from Goat Droppings

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Authors' contributions

This work was carried out in collaboration among all authors. Author LPL designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KMK and WGL supervised and managed the analyses of the study. Authors KEL, KBM and MJM managed the literature searches and conducted the experiment in the Laboratory. All authors read and approved the final manuscript.

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ABSTRACT

This experiment was conducted at the Bioenergy laboratory of Groupe de Génies Congolais (GGC) at the Université Loyola du Congo in Kinshasa, D.R.Congo. The experiment started on May 23, 2019 and ended on July 17, 2019. The study focused on the relationship between solids concentration and the kinetic of anaerobic digestion of goat droppings in the methanation process. The feedstock consisted of goat droppings waste made into slurry of four solids concentration (SC); A=50%, B=38%, C=30% and D=25%. Each SC was repeated three times. Feedstocks were inserted in laboratory scale anaerobic digesters constructed from 5L plastic containers. The results revealed clearly that the time required for the production of biogas depends on SCs. The ratio D (1/3), i.g. 75% of water and 25% of biomass produced the biogas in 3 weeks (±22 days) and the ratio A (1/1), 50% of water and 50% of biomass, in 7 weeks and a few days (±53 days). The ratio C

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(1/2), 66.6% of water in the mixture, provided the biogas in ± 26 days (approximately 4 weeks) and finally, it took ±30 days (4 weeks and a few days) for ratio B to produce biogas rich in CH_4 (<50%). The equation f(x)= 1.1x + 1 can be used to predict the approximative number of days to produce a biogas containing more than 50% of CH_4.
The average temperature inside the reactors was found to be 28.5 ± 0.8°C during the combustion testing process implying that the reactors designed at the GGC were operating in a mesophilic regime. Finally, the pH of the digestates obtained from reactors had an average of 9.0 ± 0.2.

Keywords: Methanation; biogas; ratio; water; biomass; goat droppings; biodigester.

1. INTRODUCTION

Anaerobic Digestion (AD) is a well proven process in which organic matter breaks down naturally in the absence of oxygen to produce two valuable products - biogas and digestate. Biogas is an extremely useful source of renewable energy, whilst digestate is a highly valuable biofertiliser [1]. AD process occurs naturally in the digestive system of ruminants. Ruminants (beef, mutton, goat) evacuate greater quantities of methane gas per day. Indeed, the intestinal flora of ruminant is very rich in microorganism which helps them in the digestion of food. These are especially methanogenic microorganisms which are coccoidal microorganisms (sphere-shaped) or rod-shaped. Microbes that undertake methanogenesis respire anaerobically, utilizing oxidized carbon such as CO_2 as an electron acceptor. Methanogens are found commonly in anaerobic environments which do not contain many oxygen sources, such as O_2 or NO_3^- [2,3]. The droppings generated by these animals vary in their characteristics and quantities, but are considered as potential feedstock for biomethanation. This is the man reason of the use of the cattle manure as an inoculum for the start-up of agricultural biogas plants or as a co-substrate in the anaerobic digestion of lignocellulosic feedstock [4-6].

Residues from animal husbandry are one of the major greenhouse gas (GHG) emission sources in agriculture. The production of biogas from agricultural residues can reduce GHG emissions through an improved handling of the material streams such as manure storage. For example, goat droppings can be a valuable resource if well managed. If improperly managed, it can be source of water pollution, odor, flies, parasites, and other nuisances. It can contaminate drinking water, harm wildlife, and reduce property values [7,8,9,10,11].

In Kimwenza, precisely in the jesuit community of Canisius, the management of goat droppings is well organized. The collection of manure is done every day and goat waste are used as fertilizer (Fig. 1).

Biogas is a term used to represent a mixture of different gases produced as a result of the action of anaerobic microorganisms on domestic and agricultural waste. It usually contains 50% and above methane (CH_4) and other gases in relatively low proportions namely, CO_2, H_2S, N_2 and O_2. The mixture of the gases is combustible if the methane content is more than 50% [12,13].

Fig. 1. Collection of manure at Canisius-Kimwenza goat farm. Goat droppings are an excellent fertilizer for herbs, vegetables, trees and other crops. It is known to increase the soil's ability to hold water, among other uses

The methane fraction of biogas can be utilized for electricity generation through biomethanation power plant consisting of digester, heat engine and generator. Such power plant can produce electrical power by utilizing organic wastes, including industrial, agricultural and municipal wastes. It is reported that biomethanation is a highly efficient and low cost technology [14]. During AD, organic matter goes through four main phases of decomposition, constituting the main stages of anaerobic digestion, before leading to the production of methane. These are hydrolysis, acidogenesis, acetogenesis and methanogenesis. The yield of biogas and methane depends on many parameters like feedstock type, digestion system, and retention time. Optimization of operating parameters (pH, temperature, carbon to nitrogen ratio, hydraulic retention time and inoculums) helps to maximize specific biogas yield [15-19]. Thus, the decomposition of biomass by water or hydrolysis is a key stage in the methanisation process. Hydrolysis is considered as the rate-limiting step during the anaerobic digestion of these waste streams due to their high content of lignocellulosic materials. Consequently, numerous studies have focused on the development of feedstock pretreatment methods and inoculation strategies in order to improve the hydrolytic efficiency and consequently enhance the rates of acidogenesis and methanogenesis [20,21].

The aim of this study was to produce biogas from goat droppings waste and evaluate the relationship between Solids Concentration (SC) and the kinetic of the methanation process *in-situ* using the laboratory scale anaerobic digesters constructed from 5 L plastic containers.

2. MATERIALS AND METHODS

2.1 Period of Study

This study was carried out in the Bioenergy laboratory under supervision of Groupe de Génies Congolais (GGC) at the Loyola University of Congo in Kinsahsa, D.R. Congo. The experiment started on May 23, 2019 and ended on July 17, 2019.

2.2 Sample Collection

The goat droppings were collected at Saint Pierre Canisius jesuit community in Kimwenza. It were crushed and kept in plastic containers in the laboratory.

2.3 Reactor Set Up

Biomethanation is a biochemical process that takes place in the absence of oxygen. To successfully complete this process, it was therefore necessary to set up a sealed device in anaerobic condition. As a result, a system was designed and implemented at the GGC to meet the necessary conditions promoting the production of bio-methane. 5 L containers (twelve) were used and each container connected by a hose to allow the passage of gas at the level of the sleeve. At the junction between the container and the pipe, glue was applied in order to promote the tightness of the system. At the end of the pipe an inflatable balloon was placed to collect the gases (Fig. 2).

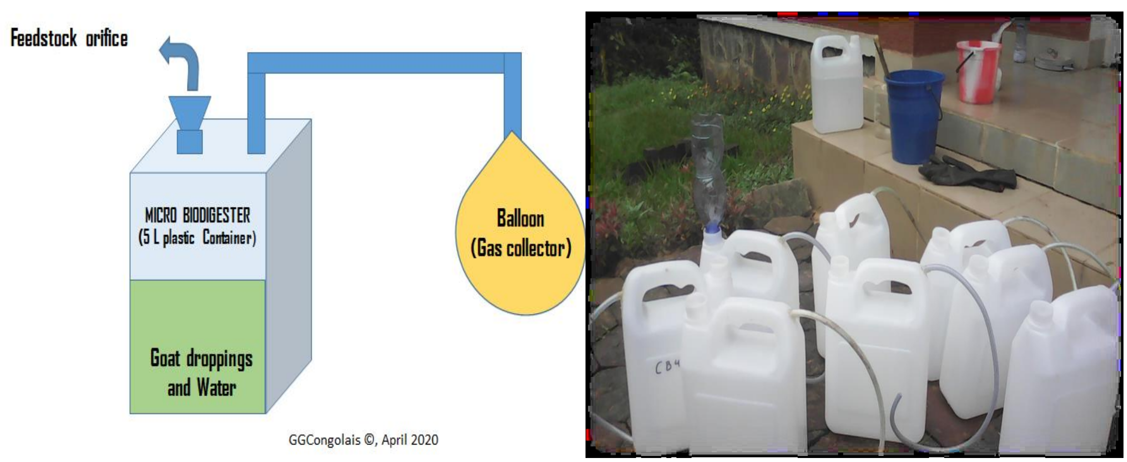

Fig. 2. Laboratory scale anaerobic digesters constructed from 5L plastic containers to assess the methanation process *in situ*

2.4 Sample Preparation, Reactor Start-Up and Feeding

The feedstock consisted of goat droppings made into slurry of four SC. Using an analytical balance (FX-2000i d = 0.01), 500 g of crushed goat droppings were weighed and placed in an empty container. The amount of droppings for each proportion used was 500 g. Note that only the quantities of water varied. A 1000 mL beaker and a 100 mL graduated cylinder were used to measure the amount of water required for each ratio. Thus, the following SC were obtained: 1/1 (500 g of biomass and 500 mL of water) which represents 50% in dry matter, 3/5 (500 g of biomass and 833 mL of water) or approximately 38% in dry matter, ½ (500 g of biomass and 1000 mL of water) equivalent to 30% in dry matter and finally 1/3 (500 g of biomass and 1500 mL of water) which represents 25% in biomass and 75% water. Each ratio was repeated three times. The feedstock was subjected to constant stirring for 10 minutes to promote good mixing. The mixture was later inserted into the anaerobic digesters constructed from 5L plastic containers (Fig. 3).

In addition, a code was assigned to all the anaerobic digesters according to the SC and the repetition. 50% SC was codified A, 38% codified B, 30% coded C and finally, 25% coded D (Table 1). Since each was repeated 3 times, a total of 12 anaerobic devices were coded as follows: A1, A2, A3, B1, B2, B3, C1, C2, C3, D1, D2 and D3. The number associated with each letter represents repetition.

2.5 Combustion Test

Biogas is a mixture of gases. This mixture is combustible if the methane content is more than 50%. Upon complete combustion, methane releases a blue flame (Fig. 4). We used a qualitative method to evaluate the production of biogas *in situ*. Thus, during the test, a persistent blue flame confirmed the presence of methane in significant proportion (50% or more).

To do the combustion test, matches were used as a ignition source. The air balloon connected to the anaerobic device was detached while taking care not to allow the gas contained in biodigester to escape. The released gas can ignite or either extinguish the flame depending on the concentration of methane (Fig. 5).

2.6 Temperature Control

A digital thermometer brand Ebro TFX 420 was inserted into the experimental biodigester (Fig. 6). The purpose was to determine the regime of the anaerobic digestion process in the laboratory scale biodigesters.

Fig. 3. The analytical balance (FX-2000i d = 0.01) and anaerobic reactors containing the feedstock at different SC

Table 1. Codification of the SCs

SCs	**A**	**B**	**C**	**D**
Quantity of goat droppings (g)	500	500	500	500
Quantity of H_2O (L)	500	833	1000	1500
% of goat droppings	50	37.5	33.3	25
% of H_2O	50	62.5	66.6	75

Fig. 4. A complete combustion of a biogas produced at GGC. The persistent blue flame confirm the presence of methane in significant proportion (50% or more)

Fig. 5. Combustion test for qualitative evaluation of biogas

Fig. 6. Temperature control inside the laboratory scale biodigesters using a digital thermometer brand Ebro TFX 420

2.7 ph Control

One of the key parameters in the methanation process is the pH. An environment that is too acidic or too basic can be an unfavorable environment for methanogenic microorganisms. The pH test was carried out using an OAKTON pH / CON 510 Series pH meter (Fig. 7). A small quantity of digestate (3 ml) was taken using a pipette and transferred to a beaker for pH determination.

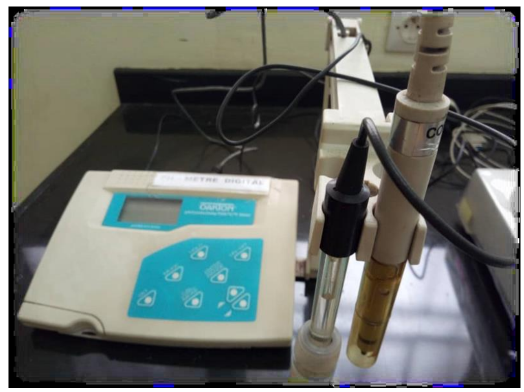

Fig. 7. Determination of pH using the OAKTON pH / CON 510 series pH meter

3. RESULTS AND DISCUSSION

The results obtained after combustion test from 23 May to 17 July as shown in Table 2 confirm that goat droppings can be used as a substrate in the production of biogas. In addition, it appears clearly that the methanation process is function of SC. The ratio D, the richest in water (75%), started producing methane gas after only ± 21 days in all three repetitions (D1, D2 and D3). However, the percentage of CH_4 in biogas was inferior to 50% on the 21st day of the experiment. Total combustion was observed after 23 days suggesting a sufficient quantity of methane (>50%). The ratio C (33.3% of biomass and 66.3% of water) started to produce gas methane after ± 24 days. However, a biogas product much richer in methane was obtained after 27 days. Proportion B (37.5% biomass and 62.5% water) began to produce biogas on day 29 in the three anaerobic devices (B1, B2 and B3). However, a significant quantity of methane with a stable flame was not observed until the 31st day.

Finally, proportion A (1/1) with 50% biomass and 50% water was the last to produce biogas. It took 49 days to observe the presence an unstable flame. The flame became stable 5 days later (54th day).

The analysis of variance (ANOVA) with EXCEL indicates that there is a statistical difference between SCs. Suggesting that SC influences the kinetic of the methanization process *in-situ*. As it can be underligned, not all 4 ratios gave a rich biogas on the same day. Ratio D was the first to produce (± 21 days), followed by C (± 26 days) and B (± 29 days). And ± 49 days for the A ratio (Table 3).

These results logically highlight the role of water in the biogas production process. Indeed, the kinetic of biogas production is a function of SC in the feedstock.

The period to produce a flammable biogas increases with with the SC. A feedstock with a less quantity of water (< 62, 5%) will lengten the period of methanation process. This experiment has given an equation (A) which can be used to predict the number of days required to produce a biogas containing more than 50% of CH_4 depending on the SC of goat droppings (Fig. 7).

$$F(x) = Y = 1.1x + 1 \quad (A)$$

Table 2. Kinetic of the methanation process *in-situ*

Dates	Solids concentration											
	50%			37.5%			33.3%			25%		
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
23/05	-	-	-	-	-	-	-	-	-	-	-	-
08/06	-	-	-	-	-	-	-	-	-	-	-	-
13/06	-	-	-	-	-	-	-	-	-	±	±	±
14/06	-	-	-	-	-	-	-	-	-	±	±	+
15/06	-	-	-	-	-	-	-	-	-	+	±	+
16/06	-	-	-	-	-	-	-	-	-	+	±	+
17/06	-	-	-	-	-	-	±	-	-	+	+	+
18/06	-	-	-	-	-	-	±	±	-	+	+	+
19/06	-	-	-	-	-	-	±	±	±	+	+	+
20/06	-	-	-	-	±	-	+	+	±	+	+	+
21/06	-	-	-	±	±	-	+	+	+	+	+	+
22/06	-	-	-	±	±	±	+	+	+	+	+	+
23/06	-	-	-	±	±	±	+	+	+	+	+	+
24/06	-	-	-	+	+	+	+	+	+	+	+	+
25/06	-	-	-	+	+	+	+	+	+	+	+	+
12/07	±	±	±	+	+	+	+	+	+	+	+	+
17/07	+	+	+	+	+	+	+	+	+	+	+	+

Legend: - means: no combustion. ± means: partial combustion, presence of blue flame but poor in Methane (< 50%). + means: total combustion, persistent blue flame rich in Methane (>50%)

Table 3. Average days in the methanation process *in-situ*

SCs	Codes	Number of days	Means
50%	A1	54	53
	A2	53	
	A3	52	
37.5%	B1	30	30
	B2	30	
	B3	30	
33.3%	C1	26	26
	C2	26	
	C3	27	
25%	D1	23	22
	D2	23	
	D3	22	

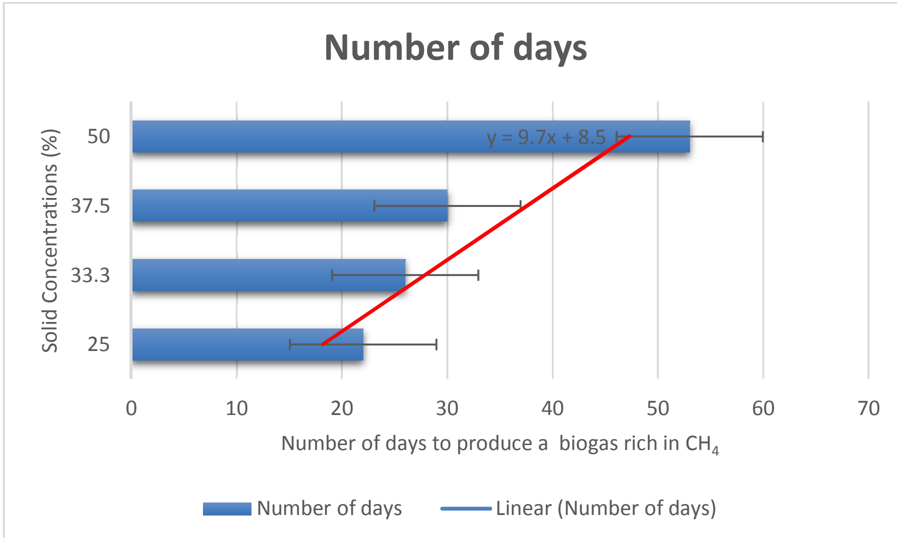

Fig. 7. Number of days to obtain a biogas rich in Methane according to different SCs is predicted using this equation: f(x)=Y= 1.1x + 1

Table 4. Temperature (°C) monitoring inside reactors during the combustion test

SCs	Codes	t°C	Means
50%	A1	28.4	28.8
	A2	27.9	
	A3	30.1	
37.5%	B1	28.0	27.9
	B2	27.6	
	B3	28.2	
33.3%	C1	30.0	28.8
	C2	27.8	
	C3	28.5	
25%	D1	29.1	28.6
	D2	28.9	
	D3	28.0	
Average temperature (°C)			28.5

Table 5. pH of digestates

SCs	Codes	pH	Means
50%	A1	9.2	9.0
	A2	8.7	
	A3	9.1	
37.5%	B1	9.0	9.0
	B2	8.6	
	B3	9.3	
33.3%	C1	9.1	9.1
	C2	9.1	
	C3	9.0	
25%	D1	8.9	9.0
	D2	9.0	
	D3	9.2	
Average pH			9.0

3.1 Temperature Measurement

The average temperature inside the reactors (Table 4) was found to be 28.5 ± 0.8°C during the combustion testing process. This result reveals that the anaerobic mini-biodigesters designed at GGC operate in a mesophilic regime (20-45°C) [22-24].

3.2 pH Measurement

The digestates obtained from the 12 experimental reactors have an approximately pH value of 9.0 ± 0.2 (Table 5). A sufficiently basic pH that allows us to plan to use the digestate as a substance to amend the soil [25-28]. Further studies will be conducted to verify this hypothesis.

4. CONCLUSION AND SUGGESTION

This study was focused on the evaluation of the relationship between solids concentration and the required time for the production of a rich biogas from goat droppings *in-situ*. The results have highlighted the role of water in the feedstock during the methanation process. It clearly appears that the time for the production of biogas depends on SCs. The ratio D (1/3), 75% of water and 25% of biomass produced the biogas in 3 weeks (22 days) and the ratio A (1/1), 50% in water and 50% in biomass, in 7 weeks and a few days (53 days). Which gives a difference of 31 days. The ratio C (1/2), 66.6% of water provided the biogas in 26 days (approximately 4 weeks) and it took 30 days (4 weeks and a few days) for the ratio B. The average temperature in the anaerobic devices was evaluated at 28.5 ± 0.8°C, which leads to the conclusion that the production of biogas in the reactors was done under mesophilic conditions. Finally, the measurement of the pH of the digestates sampled in mini-biodigesters has opened up a door for further studies. Indeed, with an average of 9.0 ± 0.2, the digestates can be used as organic fertilizer to amend the soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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