PRODUCTION OF BIOGAS FROM WATER HYACINTH: EFFECT OF SUBSTRATE LOADING IN SEMI-BATCH & BATCH OPERATIONS

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Abstract

A study was carried out to establish the effect of substrate loading rate on the production of biogas from water hyacinth. The experiments revealed that the maximum methane yield in a batch process was 0.166 normal litre (NL)/g of volatile solids (VS) added at substrate concentration of 25 g dry mass/litre after five days of incubation. The maximum methane yield in a semi-batch process was 0.153 NL/g VS added at 1.30 g VS/litre day and retention time of 15 days.

1.0 INTRODUCTION

Lake Victoria is the largest and the richest in species lake in Africa. It is also the second largest lake in the world with surface area of 680,800 km^2, a shoreline of 3450 km and a catchment area of 193,000 km^2 (Crul, 1993). However, the lake is facing three major problems, namely (i) loss of biodiversity (ii) eutrophication (iii) rapid growth of water hyacinths (van Horen, 1996; Witte *et al,* 1992; Rutashobya, 1996; Chege, 1995).

The infestation of Water Hyacinth (WH) plant in Lake Victoria has created innumerable problems to man including serious social, economic and environmental problems. It has interfered with the use of water by causing direct obstruction to navigation and by degrading water quality for domestic use (Rutashobya, 1996). It has been responsible for drastic changes in the plant and animal communities of the lake and it has served as an agent for dispersal of several deadly diseases.

Several methods have been studied in order to control the rapid growth of the plant. These include mechanical harvesting, biological as well as chemicals control. Recently, more attractive uses of Water hyacinth have been found which try to confer upon the plant the status of a resource and hence changing the weed management in concept from "the management for control" to "the management of a resource". However, utilisation of Water hyacinth such as; making compost, livestock feed supplement, upgrading wastewater treatment plants, recovery of metals, etc. do not match with the plant's growth. Control of nutrient loading into the lake and water hyacinth utilisation as a source of thermal energy and for production of ethanol, have been suggested as being possible methods of maintaining the quality of the lake Victoria water body (Masende *et al*, 1999). Conversion of biomass into methane is being conceived as a viable option with a potential of attracting more users of the plant. This paper looks at the parameters that affect the production of biogas from water hyacinth.

2.0 LITERATURE REVIEW

Among the aquatic weeds, water hyacinth has been mostly used as a substrate for methane production. Most of the anaerobic digestion systems used to convert the water hyacinth are conventional single stage system using cowdung as a feedstock. These include the continuously stirred tank reactors (CSTR) and the unstirred digesters (Ghosh and Klass, 1981; Smith et al., 1988). This paper looks on the effect of operation mode (i.e. batch and semi-batch) on the methane production from water hyacinth.

3.0 EXPERIMENTAL WORK

Water hyacinth plants were harvested at a distance of about 10 metres from the lakeshore to avoid local contamination. After harvesting all plants were cleaned to remove soil and dead plant materials and put in one heap and mixed thoroughly. Sampling was done in two ways, namely (i) Water hyacinth shoots (WHS) on which the roots were removed by cutting and the shoots were collected. (ii) Whole water hyacinth plant (WWH) on which the intact plant without cutting the roots were collected. The plants in both groups were chopped, blended by using a food blender (about 5-10mm length) and sun-dried for 5-6 days. Both materials (WHS and WWH) were stored at room temperature (25-30°C).

The inocular for batch cultures were prepared from the rumen content of slaughtered cows collected from Kimara slaughterhouse, in Dar es Salaam. The rumen liquor was strained through the cheesecloth as described by Mtila (1994). The inocular for batch and semi-batch experiments were collected from the living cow from Wageningen Agricultural University in the Netherlands.

The experimental set up was as shown in Fig. 1. The experiments were performed in 100ml serum bottles. Each experiment was duplicated. A desired substrate load was introduced into the serum bottles followed by 40 ml of water. The inoculations of 10 ml. of rumen fluid were then added in the serum bottles. The bottles were closed with n-butyl rubber stoppers and aluminium caps immediately after inoculation. The bottles were flushed with nitrogen gas for about 6 minutes to create anaerobic conditions and then incubated at 39°C in an incubator shaker, which ensured mixing of the digestion mixture during the entire incubation period.

Samples for methane and volatile fatty acids (VFA) were taken at specified time in the respective experiment. Samples for gaseous mixture were drawn from bottles by means of 1-ml gas syringes. Samples for VFA and pH determination were taken from the bottles after thoroughly mixing of the digestion mixture and put in the eppendorf vials. The pH of the digestion mixtures was measured using a digital sentron 1001 pH meter. All sample bottles were frozen below 0°C until VFA analyses.

3.1 Batch Digesters

Three laboratory-scale digesters of 1.1 litres volume (0.99 L working volume) were used in this study. Each digester was provided with a stirrer and heating coils. The inside of the digester consisted of the thermocouple probes connected to the temperature transmitter/indicator connected to the computer. The digester was provided with the magnetic valve, which was used to control the amount of sodium hydroxide added to the reacting mixture to control pH.

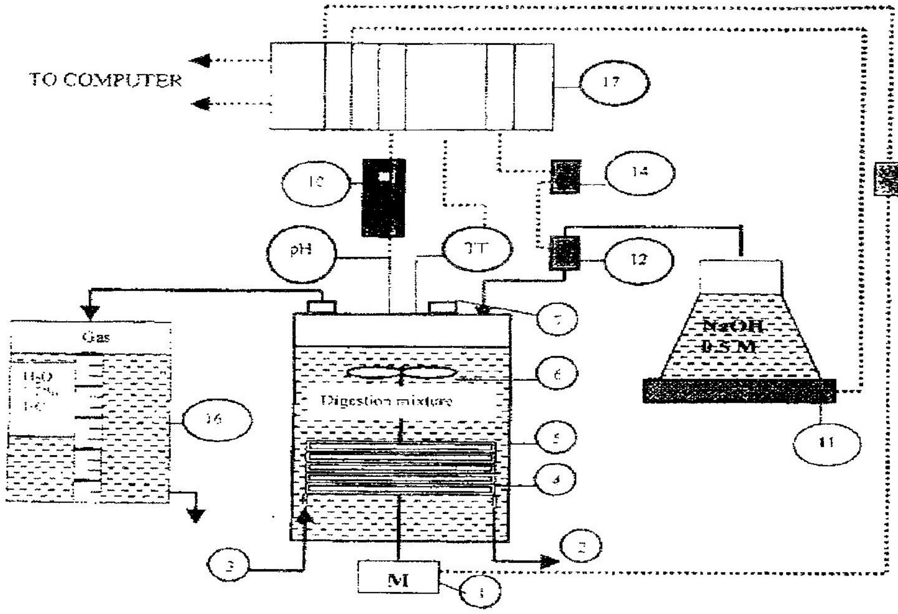
The control of pH, NaOH and the stirrer speed was computerised. The digesters operated at a temperature range of 39-40.5°C during the period of study. The temperature was controlled by a water bath. Contents of digester were stirred continuously at a range of 220-230 rpm.

The digester was provided with the calibrated marriote gas-collecting flask, which collected the gas produced by displacement of water (0.02% HCl to prevent alga formation). Sampling ports were provided to determine the gas composition in the fermentor as well as VFA content of the liquid phase.

3.2 Semi-batch Digesters

The same types of digesters were used to perform the semi-batch experiment, except the modes of feeding were changed.

A gas chromatography (GC) technique was used to analyse methane and VFA. The GC (Hewlett



Legend
1 = motor, 2 = water outlet, 3 warm water from water bath, 4 = heating coils, 5 = digester, 6 = stirrer, 7 = sampling pot, 8 = pH meter, 9 = temperature transmitter, 10 = pH transmitter/indicator, 11 = balance, 12 = magnetic valve, 13 = transmitter, 14 = magnetic valve signal transmitter, 15 = stirrer transmitter, 16 = Marriot flask, Multilab signal transmitter.

Figure. 1: Experimental set-up

Parkad 5980) was equipped with flame ionisation detector and capillary porous polymer poraPLOT Q column (25m x 0.53mm; cat. no: 7574, column no: 434670) fused with silica for methane analysis. The flame ionisation detector detected methane separated by the column while a Penelson model No. 1020 was used for the integration of the signals obtained from the detector. Helium was used as a carrier gas. A column of a Wall Coated Tubular (WCDOT) (25 x 0.2µm) fused with silica was used for the VFA analysis.

4.0 RESULTS AND DISCUSSION

4.1 Anaerobic Digestion in Batch Digesters

The results of biogas and methane production in batch digesters are as presented in Table 1. It can be seen from this table that the substrate concentration of 21.25 g dry VS/litre produced biogas yields of 0.159 L/g dry mass respectively. The methane content of the biogas produced was about 79 %v/v.

It can also be seen from Table 1 that the maximum biogas and methane yields of 0.211 L/g dry and 0.159 NL/g dry mass, respectively, were obtained after five days of digestion period. Smith *et al.* (1988) produced a methane content of 62% at 0.240 L/g TS biogas yield, which is equivalent to 0.149 NL/g TS methane yield, after a digestion period of 60 days. The differences in these two values may be attributed to the difference in C:N ratio used in the two studies. In this study, the C:N ratio was 25:1 whereas that in Smith *et al* study was 15:1. Another reason for the variation may be due the difference in operating conditions such as temperature (Smith *et al* conducted their studies at about 25°C) and different types of the inoculum used in the two studies. Mtila (1994) reported methane yield of 0.160 NL/g fresh water hyacinth after an incubation period of 60 days, which is similar to what was obtained in this study.

Table 1: Operating conditions and Methane yields of dry-ground water hyacinth shoots in a batch digester

Observed data	Units	Run 1	Run 2	Run 3	Average
A: Feed					
1. Weight of material	g	19.80	19.42	19.26	19.49
2. Solid content	%w/w	13.00	13.00	13.00	13.00
3. Volatile fraction of the solids	%w/w	85.79	85.79	85.79	85.79
B: Operating Conditions					
1. Temperature	°C	40±0.2	39±0.2	39±0.2	39.3±0.2
2. pH	-	7.35±0.5	7.50±0.5	7.4±0.5	7.42±0.5
3. Duration	Days	6	6	6	6
4. Volatile loading	g dry VS/L.day	21.45	20.87	21.44	21.25
C: Biogas yields					
1. Total biogas collect	L	3.70	4.00	3.60	3.78
2. Average daily gas production	L/day	0.63	0.66	0.61	0.63
3. Biogas yield	L/g dry VS added	0.218	0.216	0.200	0.211
D: Methane yields					
1. Methane content	%v/v	79	78	80	79
2. Total methane collected	NL	2.55	2.18	2.28	2.34
3. Methane production rate	NL/L.day	0.43	0.36	0.37	0.39
4. Methane yield	NL/g VS added	0.166	0.146	0.165	0.159

4.2 Anaerobic Digestion in a Semi-Batch Digester

The results of biogas and methane production in the semi-batch digesters are presented in Table 2. It can be seen from table 2 that methane yield of about 0.153 NL/g dry VS at a volatile solids loading rate of about 1.3g dry VS/L.day. The observed increase in methane production which resulted from increased loading rate may be attributed to the increase in the availability of easily degradable materials in the substrate. At a maximum dry volatile solids loading rate of 1.3g/litre.day and a hydraulic retention time of 15 days the maximum methane yield of 0.153 NL/g VS was obtained.

Delgado *et al* (1992) in their study applied the loading rate of 0.84g VS/L.day of dry water hyacinth and obtained biogas yield of 0.292 L/g VS added (equivalent to 0.175NL/g VS methane yield), which is higher than that obtained in this study. The variation may be attributed to different operating conditions. For example, Delgado *et al* recycled the effluent to the digester thereby maintaining a high population of the micro-organisms required for anaerobic digestion. There was no effluent recycling in this study. Casebow (1967) obtained optimal loading rate of 1.619g dry VS/L day at hydraulic retention time of 30 days, which was similar to the optimal value established in this study. Kivaisi and Mtila (1998) obtained the loading rate of 15.4g VS/L.day (WHS-cow-dung mixture in the ratio of 7:3) at a retention time of 90 hours in the rumen reactor. Their methanogenic reactor was connected to the up-flow anaerobic sludge blanket (UAAB) reactor and methane yield was 0.44 L/g VS digested. These values were very high comparing to the values obtained in this study, which may be attributed to the difference in substrate composition, type of the digesters used and operating conditions employed in both studies.

Table 2: Operating conditions and Methane yields of dry ground water hyacinth shoots in a Semi-batch

Observed data	Units	Run1	Run 2	Run 3	Run 4	Run 5	Run 6
A: Feed							
1. Solid content	%w/w	13.00	13.00	13.00	13.00	13.00	13.00
2. Volatile solids content	%w/w	85.79	85.79	85.79	85.79	85.79	85.79
B: Operating Conditions							
1. Temperature	^{o}C	40±0.2	39±0.2	39±0.2	40±0.2	39±0.2	39±0.2
2. pH	-	7.0±0.5	7.0±0.5	7.0±0.5	7.0±0.5	7.0±0.5	7.0±0.5
3. Volatile loading rate	g/dry VS /L.day	1.30	1.29	1.30	1.28	1.31	1.30
4. Hydraulic retention time	Days	30	30	29	29	28	30
C: Biogas yields							
1. Biogas production rate	L/L.day	0.42	0.40	0.41	0.42	0.43	0.42
2. Biogas yield	L/g dry VS added	0.225	0.215	0.226	0.215	0.223	0.230
3. Specific biogas production	L/g dry VS added.day	0.0150	0.0150	0.0163	0.0154	0.0144	0.0146
D: Methane yields							
1. Methane content	V/v%	68	67	63	68	69	69
2. Methane production rate	NL/L.day	0.286	0.255	0.252	0.280	0.260	0.287
3. Methane yield	NL/g dry VS added	0.153	0.151	0.156	0.152	0.160	0.152
4. Specific methane production	NL/g dry VS added.day	0.010	0.0120	0.0103	0.010	0.012	0.010

Specific methane production rate increased with increasing volatile solid loading rate. In this study maximum specific methane production rate achieved was 0.012 NL/g dry VS added day at the highest volatile loading rate of 1.3g VS/L.day and lowest retention time of 15 days. Gopal (1987) reported specific methane production rate of 0.0063NL/g dry VS.day, which is also different from the values obtained in this study. Again, the variations may be attributed to the amount of volatile solids available in the substrates. Their substrate had low VS content (74%) compared to Lake Victoria substrate (85.79%) while the C:N ratio was lower (16:1) compared to 25:1.

5.0 CONCLUSIONS

There was no significant influence of loading mechanism on methane yield. This should be expected since the amount of methane produced is a function of available fermentable sugars. The only advantage of a semi-batch reactor over the batch one could be the high micro-organisms population present in the reactor, especially if the effluent is recycled. It should be noted that in this study there was no effluent recycling and thus the yield is almost the same in both cases.

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