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Impact of Water Hyacinth (*Eicchornia crassipes*) as a Feedstock for Biogas Production

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Abstract: Globally, biogas is considered as a clean and renewable form of energy that could replace the increasing non-renewable energy usages. In view of this, there is an increasing demand for energy crops and animal manures for an eco-friendly energy source to supplement fossil fuel, aid in heat production and for electricity generation. Biochemical methane potential test is generally used to determine the possible methane that can be obtained from feedstocks. This study, however, aims at optimizing the anaerobic digestion of water hyacinth, *Eicchornia crassipes* with cattle manure in a biochemical methane potential test, controlled at mesophilic temperature (37 ± 1). Biodigester A (with the least methane yield) contained only the inoculum and was used as the blank, biodigester B (1:1 feedstock to inoculum ratio) and biodigester C (highest methane yield at 1:4 feedstocks to inoculum ratio) contained both the inoculum and the feedstock at different loading rates. Methane production was measured for a retention period of 30 days using three 1000ml Schott bottles as biodigesters in batch mode. *Eicchornia crassipes* was characterized in the batch reactor to enable the inoculum activity and the biogas volume reported during the 30 days. Qualitatively, the highest methane composition was found to be 60% whiles quantitatively, the cumulative average methane yield was 77ml throughout the study. The higher yield of methane observed in this study gives an indication of lower cost in the purification of the carbon dioxide from the produced biogas to be used in biofuels for electricity generation and also for combined heat and power production. Therefore, water hyacinth has the potential to produce biomethane which can be used to ease the dependency on fossil fuel derived energy and as an alternative energy source for combined heat and energy which is eco-friendly.

Keywords: Biogas, Renewable Energy, Biochemical Methane Potential, Anaerobic Digestion, Water Hyacinth

1. Introduction

Renewable energy still remains a vital demand to cater for the ever-increasing energy consumption and the depletion of fossil resources from non-renewable energy [1]. According to Gu, et al. [2], studies have been carried out to find renewable energy sources as fossil fuel replacement. Also, urbanization has led to an increase in landfills and it is estimated that by 2025, two-thirds of people will be living in the cities globally [3]. For decades, the synthesis of a renewable energy source as an alternative to non-renewable energy source has been evaluated, where energy is produced from biogas through anaerobic digestion process [4]. The anaerobic digestion process to produce bioenergy has thus gained increasing recognition for the past decades. Biogas is a renewable fuel that consists chiefly of 60-70% methane and 20-30% carbon dioxide even though other traces such as hydrogen sulphide and ammonia are present. The gas produced could serve as fuel for electricity generation and also in the production of combined heat and power generation using appropriate technologies [5].

The anaerobic digestion (AD) process from which biogas is produced basically involves four main stages as a result of the biodegradation of organic matter by a consortium of microorganisms [6]. The first stage, hydrolysis, is the rate-determining step where carbohydrates, proteins, and fats present in the biomass converted to glucose, amino acids, and fatty acids respectively. Acidogenesis involves the conversion of these products to volatile fatty acids by acidogenic bacteria. The volatile acid products are then converted to carbon dioxide, hydrogen and acetates by acetogenic bacteria then finally the carbon dioxide produced can react with the hydrogen present to produce methane or the acetate breaks down to form methane and carbon dioxide with other trace compounds [7, 8]. Comparatively, anaerobes have been found to be most active at mesophilic temperatures than thermophilic temperatures as the latter tend to require higher heat input and thus, this study focused on the former [9].

Certain drawbacks have limited the full exploitation of the anaerobic digestion process such as reactor failure and process instability [10]. Processes such as co-digestion, minimal feedstock loading rate without over feeding the microorganisms, pretreatment methods, and the use of energy crops as feedstocks, have increased the efficacy of biogas production through anaerobic digestion [11-13]. Recirculation of digested slurry and design modification of existing biogas plants are some of the ways to also improve the gas production in biogas plants [14].

BMP tests are usually carried out to determine the possible methane that can be obtained from the feedstocks, largely at laboratory scale batch systems [15]. It thus aids in optimizing processes and establishing the profitability of the AD plants in terms of yield and gas quality in relation to the feedstock used [16].

Some aquatic plants have been established as more efficient in utilizing solar energy than terrestrial plants. Among these is water hyacinth as a result of its rapid growth [17], and also as a good substrate for biogas production, receiving recognition for the past few decades [18, 19]. Water hyacinth (*Eicchornia crassipes)* is an invasive water weed and a floating plant that thrives in fresh water bodies causing serious environmental problems [20]. There is a need however for the development of value addition and economic exploitation strategies on various energy crops without the competition for arable land. For the past few decades, millions of dollars are spent on water hyacinth control [21]. Water hyacinth was first reported in South Africa on the Cape flats in the early 1900s and has spread throughout the country [20]. A negative effect of this energy crop is the interference with water utilization for activities such as recreation or irrigation [22].

In view of this, the present study was carried out to determine the impact of water hyacinth (*Eicchornia crassipes*) as a feedstock for biogas production in a biochemical methane potential test under mesophilic anaerobic digestion.

2. Materials and Methods

The biochemical methane potential test was carried out to determine the potential of the water hyacinth, *Eicchornia crassipes* (shown in Figure 1) with cattle manure as the inoculum.

Figure 1. *Harvested water hyacinth (Eicchornia crassipes).*

2.1. Material Sampling and Chemicals Used

Water hyacinth (*Eicchornia crassipes*) was harvested from a local farm land near Half Assini in the Jomoro District of the Western Region of Ghana and used as the main feedstock for the biogas production. The choice of feedstock was due to the bioavailability of the feedstock in the area. The fresh cattle manure used as inoculum was obtained from a cattle farm to provide the necessary bacteria for the digestion process. Sodium hydroxide (NaOH) was used to adjust the pH of the anaerobic digestion process to cater for volatile acids that may be generated within an optimum pH of 6.5-7.5, required for the process.

It has been observed from a study that volatile fatty acids production rate is much higher than the methane production rate and could result in pH levels below the optimum range, thereby inhibiting methanogens. This is attributed to the higher level of sensitivity to acidic conditions [6]. Deionized water was also used to prepare the solutions and cleaning the equipment. Nitrogen (N_2) gas was used to purge the entire system to create the anaerobic digestion environment. The inoculum was kept in a sealed schott bottles, stored at 4°C in a refrigerator until further chemical analysis.

2.2. Feeding Rates of Feedstocks and Inoculum

Biodigesters were fed gradually according to Table 1 and kept in a circulating water bath operating at a mesophilic temperature of 35 ± 1°C. Biogas production was measured at five-day intervals up to a 30-day by water displacement technique

Table 1. *Experimental design for the feedstock and the Inoculum.*

Biodigester ID	Feedstock: Water hyacinth (% RM)	Inoculum (cattle manure)
A	0	100
B	50	50
C	25	75

2.3. Primary Characterization

The feedstock (water hyacinth) was washed and dried to remove the unwanted particles. Furthermore, it was shredded and milled to obtain a particle size of 10 mm. This was done to increase the surface area for adsorption by the during the anaerobic digestion process and to make the microorganisms accessible for degradation.

2.4. Feedstock and Inoculum Characterization

The raw feedstock was characterized and analyzed for total solids, moisture content, volatile solids, and ash contents in accordance with the standard methods [23]. All procedures were carried out in the Laboratory using a precision balance for weighing the masses, a convection oven for drying feedstock and inoculum and a muffle furnace for the ashing process. The weight loss was determined after oven drying in an oven regulated at 105°C to a constant weight. After feeding the biodigesters at an optimal loading rate as in Table 1, it was observed that the pH in each biodigester was almost as that reported by Maile, et al. [24] where $CaCO_3$ and NaOH were used to control the alkalinity during the anaerobic digestion.

2.5. Experimental Setup and Procedure

The total solids and volatile solids of the feedstocks and inoculum were pre-determined and used to prepare the digestion samples into the 1000ml schott bottles (used as the biodigesters) with an effective volume of 800-ml. For each run, a headspace of 200ml was left which was purged with N_2 to create the anaerobic environment within the biodigesters as shown in Figure 2. The biodigesters were closed air-tight with rubber caps and incubated in a circulating water bath. Since it is a batch system, it was made to run until anaerobic digestion was complete.

According to Nges [10], nutrients in the form of trace metals are added in biodigesters to improve the efficiency and stability during the anaerobic digestion process in mono-digestion. In this study, however, trace metals were absent throughout as none was added in each of the biodigesters. Stirring was carried out periodically by cautiously shaking each biodigester to ensure uniformity. The composition of biogas was analyzed from the BMP test using a gas chromatograph (SRI 8610 GC) equipped with thermal conductivity detector, packed with 6' Hayesep-D/6' Molecular Sieve-13 X. The anaerobic digestion system was designed to quantitatively determine the volume of biogas produced using a water displacement technique and qualitatively for methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S).

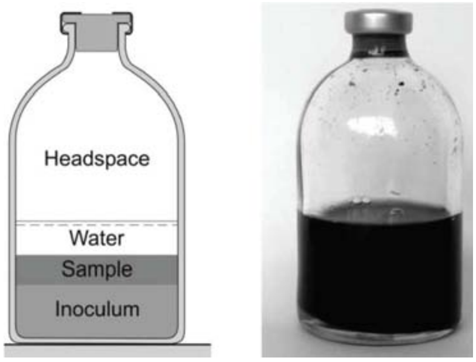

Figure 2. *The Biochemical methane potential test with loading rates of inoculum and feedstock for each biodigester.*

3. Results

The cumulative data obtained from the study is represented in Table 2 to Table 5. Following are the various graphical plots obtained from the data

Table 2. *Cumulative biogas production (ml) versus the retention time (days).*

Retention Time (days)	Volume of Biogas (ml)
5	0
10	50
15	100
20	211
25	233
30	252

Table 3. *Percentage composition of CH_4 and CO_2 for each biodigester.*

Biodigesters	% composition of CH_4	% composition of CO_2
A	41	50
B	59	40
C	60	36

Table 4. *Cumulative volume of CH_4 and CO_2 yield (in ml) for each five-day interval.*

Retention time (days)	Volume of CH_4	Volume of CO_2
5	0	0
10	28	12
15	59	33
20	115	77
25	121	89
30	136	101

Table 5. *Cumulative volume of CH_4 and CO_2 yield (in ml/d) for each five-day interval.*

Retention time (days)	Volume of CH_4	Volume of CO_2
5	0	0
10	2.8	1.2
15	3.9	2.2
20	5.7	3.9
25	4.8	3.6
30	4.4	3.4

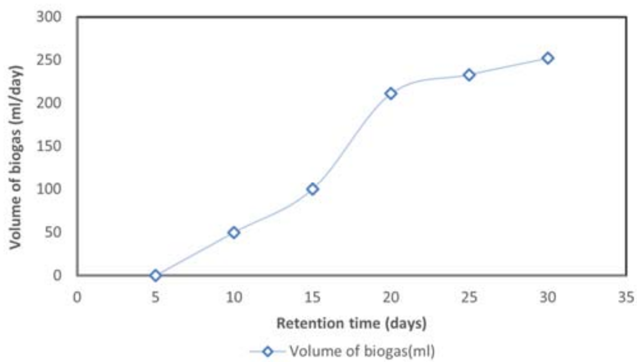

Figure 3. *Cumulative biogas production (ml) versus the retention time (days).*

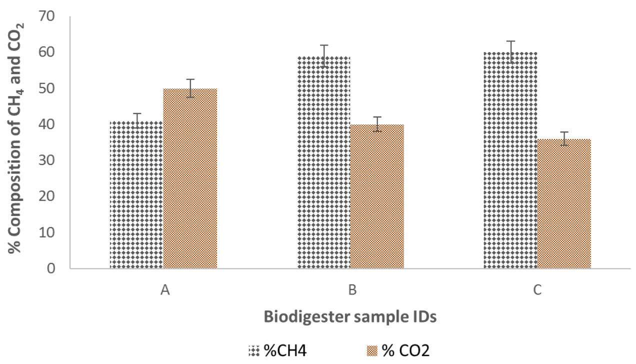

Figure 4. *Percentage composition of CH_4 and CO_2 for each biodigester.*

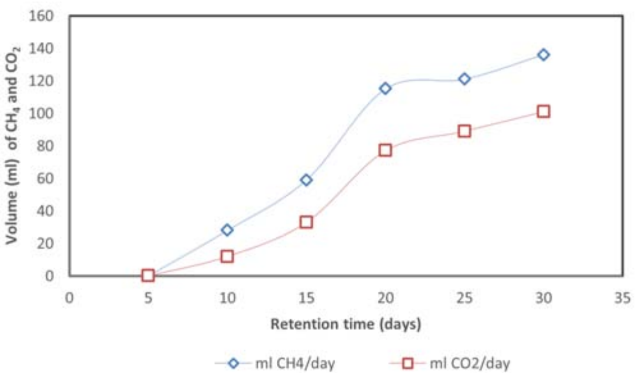

Figure 5. *Cumulative CH_4 and CO_2 yield (in ml) for each five day interval.*

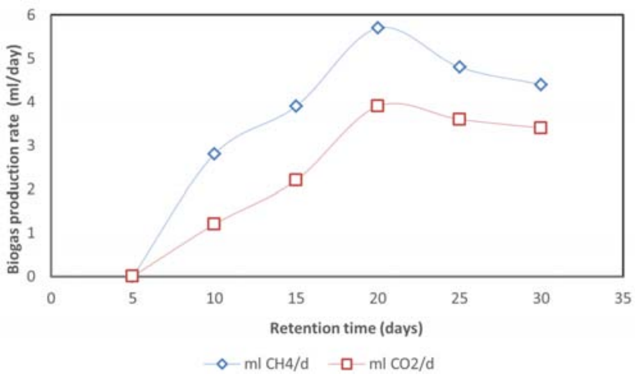

Figure 6. *Biogas production rate of CH_4 and CO_2 with respect to the volume per day.*

4. Discussion

Water hyacinth is predominant in the study area and was used for this study without the competition for arable land. In this study, the hydraulic retention time for the anaerobic digestion of the water hyacinth and the cattle manure was longer (30 days) as in Figure 2 compared to that reported by [19] in a similar study. A headspace of 200ml allowed for the collection of biogas from each biodigester which was further analysed quantitatively and qualitatively. At the beginning of the experiment, the biogas production was relatively slower and was observed to be collected after day 5 as shown in Figure 2. This is due to the lag phase process by the microorganisms within each biodigester acclimatizes to the conditions and environment within the biodigester.

The lag phase of microorganisms has been found to be decreased by the use of ionic liquids for feedstock pretreatment [25], a method which was not used in this study. Figure 2 shows the cumulative biogas production during the 30 days. The normal biogas production rate started after the fifth day of the BMP test followed by a gradual increase up to day 30 where the daily production decreased until the whole process stopped.

This study however focused and reported for data based on the actual running time of the test and did not report values after the 30 days where the process ceased. In Figure 3, it was observed that biodigester A containing only the inoculum recorded a lower methane yield as compared to the biodigesters B and C which contained both inoculum and feedstock. This could be due to the fact that, since no feedstock was added for degradation, the microorganisms only produced the amount of methane required of them. Biodigesters B and C recorded similar values except that their loading rate was different as shown in Table 1.

It was however observed from this study that process parameters such as organic loading rate, hydraulic retention time, temperature and pH play an active role in the anaerobic digestion process. Biodigester B and biodigester C recorded percentage composition of 59% and 60% methane respectively. This gives an indication that an organic loading with a higher amount of inoculum than feedstock (1:4) favours the anaerobic digestion process than for a 1:1 ratio of inoculum and feedstock. It has been found in a study that the rate of methane increases after the chemical absorption of carbon dioxide at higher concentrations of sodium hydroxide (NaOH) [26]. In the same study, it was observed that an increase in the concentration of NaOH leads to an increase in carbon dioxide (CO_2) absorption. The removal efficiency were 66% and 23% for 1M and 3M NaOH respectively [26]. Figure 5 shows a sharp rise of biogas production from day 5 and continually increase until a maximum yield reached at day 20 for both methane and carbon dioxide yield.

The higher yield of methane observed in this study gives an indication of lower cost in the purification of the carbon dioxide from the produced biogas to be used in biofuels for electricity generation and also for combined heat and power production.

5. Conclusion

Biogas production from water hyacinth, *Eicchornia crassipes* with cattle manure was studied to determine the biochemical methane potential at laboratory scale in a batch mode. This study showed that pH plays an integral role in the anaerobic digestion process and thus the optimum range should be maintained throughout the process due to volatile acids produced during the acidogenesis stage. Qualitatively, the highest methane composition was found to be 60% whiles quantitatively, the average biogas yield was 77ml. It was observed from the study that the biodigester containing only the inoculum generated less amount of methane that biodigesters that contained both the inoculum and the feedstock. The higher yield of methane observed in this study gives an indication of lower cost in the purification of the carbon dioxide from the produced biogas to be used in biofuels for electricity generation and also for combined heat and power production. Therefore, water hyacinth has the potential to produce biomethane which can be used to ease the dependency on fossil fuel derived energy and as an alternative energy source for combined heat and energy which is eco-friendly. Also, anaerobic digestion in this study at mesophilic temperatures was found to be a viable process for biogas production. It is, however, necessary for researchers to study the various inhibitors that interfere with the anaerobic digestion process and certain drawbacks that have limited the full exploitation of the process in the past decades for higher methane yield.

Conflict of Interest

All the authors do not have any possible conflicts of interest.

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