African Journal of Rural Development, Vol. 3 (2): April-June 2018: pp.769-778. ISSN 2415-2838

Assessing the potential of water hyacinth for biogas production

M. EDIMU[1], A. ATWINE[2], W. MASIKO[2], P. R. KAWUKI[1] and P. ATIM[1]
[1]Research and Education Agency, P.O. Box 29512, Kampala, Uganda
[2]Department of Electrical Engineering, Makerere University, P.O. Box 7062, Kampala, Uganda
Corresponding Author: m.edimu@rae.ac.ug, miltonedimu@yahoo.com

ABSTRACT

Nalubaale hydro power station, previously known as Owen Falls dam, is the most critical generating power plant in Uganda with installed capacity of 180MW. However, water hyacinth clogs the water intakes and disrupts power generation. Despite different initiatives to utilize this weed as a resource, an average of 54 tons of water hyacinth is still harvested on a daily basis and transported to a disposal site. The research presented here looks into the possibility of extracting biogas energy from it. The research involved the evaluation of the characteristics of water hyacinth (*Eichhornia crassipes*) as a suitable feedstock for biogas generation. Using a laboratory set up, biogas was generated from of the water hyacinth. Different setups were considered to ascertain the most suitable digestion conditions which yield the best gas volume and best gas quality. Gas analysis was performed to determine the gas quality and the amount of energy that can be generated from the biogas. This paper also assessed the viability of large scale production of biogas energy from water hyacinth and performed a cost-benefit analysis to ascertain the economic acceptability of the project. Water hyacinth exhibits characteristics of a good feedstock for biogas generation. It has an acidic pH of 5.85 which is near neutral (7.0). Water hyacinth also has 88.58% total volatile solids and total solids of 7.89%. The setup with optimum conditions contained 170g of water hyacinth, 55g of cow dung and 225ml of water and produced 3.2 liters of biogas with 60.1% methane. This is suitable for electricity generation. Using a steam turbine energy conversion system, 23.9MWh of energy can be generated monthly from the 1641.92 tons of water hyacinth harvested. The amount of energy generated can service about 305 domestic households in Uganda with an average monthly energy consumption of 78.1kWh.

Key words: Biogas energy, *Eichhornia crassipes*, electricity access, Nalubaale Hydro-power station, renewable energy

RÉSUMÉ

La centrale hydroélectrique de Nalubaale, anciennement connue sous le nom de barrage d'Owen Falls, est la centrale la plus critique en Ouganda avec une capacité installée de 180 MW. Cependant, la jacinthe d'eau obstrue les prises d'eau et perturbe la production d'électricité. Malgré différentes initiatives visant à utiliser cet adventice comme ressource, une moyenne de 54 tonnes de jacinthes d'eau est toujours récoltée quotidiennement et transportée vers un site d'élimination. La présente recherche a étudié la possibilité d'en extraire l'énergie du biogaz. La recherche a porté sur l'évaluation des caractéristiques de la jacinthe d'eau (*Eichhornia crassipes*) en tant que matière première appropriée pour la production de biogaz. En utilisant un laboratoire mis en place, le biogaz a été généré à

Cite as: Edimu, M., Atwine, A., Masiko, W., Kawuki, P. R. and Atim, P. 2018. Assessing the potential of water hyacinth for biogas production. *African Journal of Rural Development* 3 (2): 769-778.

Received: 12 January 2018
Accepted: 10 April 2018
Published: 30 June 2018

partir de la jacinthe d'eau. Différentes configurations ont été considérées pour déterminer les conditions de digestion les plus appropriées, permettant d'obtenir le meilleur volume et la meilleure qualité de gaz. Une analyse du gaz a été réalisée pour déterminer la qualité du gaz et la quantité d'énergie pouvant être générée à partir du biogaz. Ce document évaluait également la viabilité de la production à grande échelle d'énergie biogaz à partir de jacinthes d'eau et réalisait une analyse coûts-avantages pour déterminer l'acceptabilité économique du projet. La jacinthe d'eau présentait les caractéristiques d'une bonne matière première pour la production de biogaz. Son pH acide de 5,85 est presque neutre (7,0). La jacinthe d'eau contient également 88,58% de matières solides volatiles et 7,89% de solides totales. La configuration avec les conditions optimales contenait 170 g de jacinthe d'eau, 55 g de bouse de vache et 225 ml d'eau et produisait 3,2 litres de biogaz avec 60,1% de méthane. Ceci convient à la production d'électricité. En utilisant un système de conversion d'énergie à turbine à vapeur, 23,9 MWh d'énergie peuvent être générés mensuellement à partir des 1641,92 tonnes de jacinthes d'eau récoltées. La quantité d'énergie générée peut desservir environ 305 ménages en Ouganda avec une consommation d'énergie mensuelle moyenne de 78,1 kWh.

Mots clés: énergie biogaz, Eichhornia crassipes, accès à l'électricité, centrale hydroélectrique de Nalubaale, énergie renouvelable

INTRODUCTION

Water hyacinth is a tropical invasive water weed that thrives in fresh water bodies jamming rivers and lakes with tons of floating vegetation and causing serious adverse effects to aquatic life. In Uganda, it invaded the Lake Victoria waters in 1989 (Wawire, 2004) and has since caused socioeconomic and environmental problems such a clogging water supply intakes and port facilities. Most critically, it impacts on the power generation at Nalubaale hydropower station. The 64 year old power plant was until most recently the largest generating plant in Uganda. Most of Uganda's critical transmission lines emanate from it and drop into a number of transmission 132/33 kV substations. Uganda's peak demand in 2018 reached 600 MW. The hydropower plants installed capacity is 180 MW; almost 30% of the countries peak demand.

Distributed generation (DG) is the production of power close to or at the customer consumption point. As such, DG is usually connected to the distribution network. Uganda has seen a big demand for renewable energy (RE) penetration over the last five years. While the typical RE sources such as solar and wind have been accounted for in the planned supply quota, large scale generation from biogas has not been given much consideration. This may be attributed to the limitations associated with availability sufficient and sustainable quantities of feedstock and, the fact that use of agro-based feedstock will impact on local food security and the food export industry. Use of water hyacinth overcomes these limitationsAbout 17,230 hectares of the lake were infested with water hyacinth in 2005. Different methods have been proposed for the management of the weed. Chemical control while effective, poses a danger due to the type of chemical herbicides required that could lead to illness of fishermen and also change the properties of the water body thus affecting the ecosystem in the water (Opande, 2004). Pest control has been implemented in Uganda with no significant progress reported. This may be attributed to the rapid spread of the weed which can double its surface area in 6 to 15 days (Frazier, 2014). This has left Uganda with manual or mechanical means where the weeds are harvested and dumped at different landing sites around Nalubaale dam, Port Bell, Gabba and along the lake shores in Entebe.

LITERATURE REVIEW

Various research studies have been performed that sought to utilize the weed. A summary of the different applications of water hyacinth that range from use as a fertilizer, sewerage purifier, paper and reed raw material and as a food supplement, is presented by (Ting *et al.,* 2018). Specific to application in the production of biogas, countries such as Brazil, Sudan, Nigeria, Kenya and India have explored the possibility of using water hyacinth as a feedstock to produce biogas through anaerobic digestion. Water hyacinth is rich in carbon nitrogen. This makes it a potential feedstock for biogas production. A study carried out in Nigeria where the water hyacinth was blended with cow dung and poultry droppings in a ratio of 2:2:1 yielded 3.07 litres of biogas with methane as high as 62.14% from 2.5 kg of combined waste (Frazier, 2014). The study in Kenya at the Jomo Kenyatta University of Agriculture and Technology equally yielded combustible gas with a methane content of 53% from a blend of water hyacinth and cow dung in a ratio of 3:1 respectively and the resultant mixed with water in a ratio of 1:1(Njogu *et al.,* 2016). The gas was further upgraded in quality to 70%-76% methane content using solid adsorbents and wet scrubbers for gas cleaning. The biogas was then used for electricity generation using and internal combustion engine and generator.
In India, their research has gone further to add banana peels, cassava peels, poultry litter and cow dung to producing biogas with methane as high as 60% without applas cleaning (Patil *et al.,* 2014).

This study explores the possibility of utilizing the weed in biogas production. It compares water hyacinth samples from different areas in Uganda to confirm consistency in material composition, confirms the required properties for biogas generation, quantifies the percentage of methane achievable and attempts to size a DG that would generate power from the weed.

RESEARCH METHODOLOGY

Assessing sustainability of water hyacinth as an energy source. It was important to determine the spread of water hyacinth in Lake Victoria at Nalubaale Dam in terms of cover area and weight harvested regularly. The spread of water hyacinth at the study area (Nalubaale Power Station) was carried out with the intention of determining how much waste in terms water hyacinth is available to support the project. This was achieved through a review of already existing monthly reports compiled by ESKOM, operators of the power station, for the last 3 years (2015-2017). The reports contained information showing how much water hyacinth is harvested monthly in tonnage. From this information, the study computed the average amount of water hyacinth harvested annually. Personnel from the contractor in charge of managing the water hyacinth were also interviewed using a questionnaire. The objective was to determine the cost of managing this waste, how spread the water hyacinth is at the dam intake of Nalubaale, the harvesting frequency, disposal method and quantity of weed per harvest or in a specific period. This data was important to ascertain how much water hyacinth is available to the project, the bio gas production capacity within set time periods (weekly, monthly and yearly) and the associated costs of providing the feedstock.

Assessing the potential of water hyacinth for biogas production. In order produce biogas, water hyacinth plant characterization was first carried out on two samples from two different location, Gabba landing site and Nalubaale dam. The characterization was based on three criteria; the PH level, total solid value and volatile solid value. These tests were performed to confirm the suitability of Uganda's water hyacinth as a feedstock for biogas production.

Biogas production was then carried out in four sets of experiments. Each set of experiments was run under different conditions to show how biogas formation from water hyacinth varies under different conditions as shown in Table 1.

The use of cow dung as an additive in biogas production has been demonstrated with other agro-based inputs such as cow pea and cassava peelings (Ukpali and Nnabuchi, 2012).

Table 1. Experiments carried out under different conditions

Setup	Sample	Conditions	Mixing ratio	Rationale for the Test
1	1, 2 & 3	Near neutral PH $35^{S}C$ Co-digestion using cow dung	(WH:CD) : (H_2O) (3:1) : (1)	To check gas produce under optimum conditions To get gas produced under co-digestion
2	4	Near neutral PH $35^{o}C$ No Cow dung added	WH : H_2O 1 : 1	To check gas produced without co-digestion
3	5	Near neutral PH Room temperature Co-digestion using cow dung	(WH:CD) : (H_2O) (3:1) : (1)	To check the gas produced under room temperature
4	6	Near neutral PH $35^{o}C$ Co-digestion using cow dung	(WH:CD) : (H_2O) (3:1) : (1) .	To check the methane formation over time

Figure 1. Actual Biogas production setup

It was expected that each set of experiment would yield different biogas quality and quantity over time. The purpose here was to determine the most favourable conditions for biogas production from water hyacinth. The actual set up is shown in Figures 1.

The water hyacinth was crushed to attain homogeneity and also increase surface area for the bacteria to act. This increases the rate at which biogas is generated.

The crushed water hyacinth was fed into the digester which is placed in a water bath at 35 degrees Celsius. This temperature is the optimum for the bacteria to act under mesophilic conditions. When the biogas is formed, it moves from the digester to the gas collector and displaces the water in the collector as shown above. The displaced water is equivalent to the volume of the gas in the collector. The water is displaced into a beaker which takes the measurement in milliliters. The gas output form the digester was measured every 3 days in ml through measuring the amount of water displaced from the gas collector into the beaker. Gas analysis was carried out at the end of the retention period with the exception of the reference sample where gas analysis was carried out every 5 days to check the methane formation level over the spread of the entire retention period. Gas analysis was done using a gas analyzer which sucks in a bit of gas from the collector through a tube. The gas was analyzed internally in the analyzer and displayed the biogas composition in different percentages on the LCD screen.

STUDY RESULTS

Assessing sustainability of water hyacinth as an energy source. The water Hyacinth coverage at NPS could not be estimated because it is collected on a daily basis. It simply floats and is held back by the dam wall. The water hyacinth collected depends on the weather patterns as it is more during rainy seasons compared to dry seasons. The average monthly water hyacinth harvested was 1641.92 tons (Eskom, Report). The harvesting and dumping of the water hyacinth is executed by private contractors at a cost of about USD 4110 monthly. The average monthly water hyacinth harvest over the last three years (2015-2017) as shown in Figure 2.

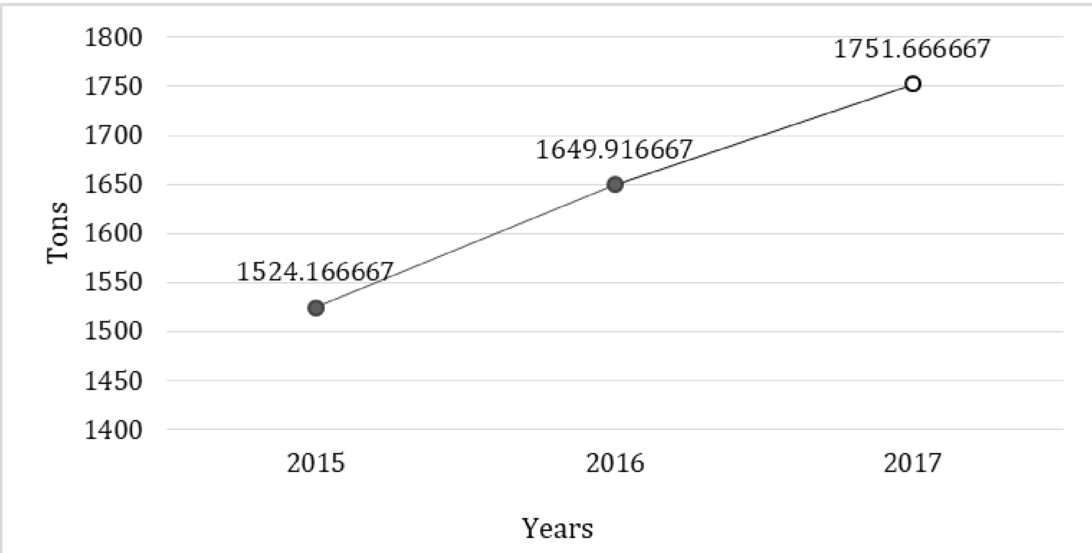

Figure 2. Average Monthly Harvest 2015-2017

From the findings obtained in Jinja, it was realized that water hyacinth is readily available as a source of biomass to facilitate biogas production at NPS without even considering the other parts of Lake Victoria that are highly vested with this weed. The graph presented above shows an increase in the average monthly harvest of water hyacinth over the past 3 years.

Assessing potential of Uganda's water hyacinth for biogas production. The first step included water hyacinth Characterization. Samples of water hyacinth were collected from Jinja Eastern Uganda . Tests were carried out on the water hyacinth to determine its suitability to generate biogas. The tests included the total solid test, total volatile solid test and PH test. As part of this Total Solid Test was done. This estimated the moisture content of the waste and how much water would have to be added during the mixing process for digestion. Water hyacinth was diced and the weight of the three samples measured. The samples were then dried in an oven as shown in figure 4 for 3 days at 69°C to remove all the moisture and the new weights were taken. The new percentage weight of each sample was obtained. The results are presented in Table 2. An average of the three samples, 7.86%, was computed and considered as the total solid value for the water hyacinth from Jinja.

For optimal bio digestion the total solid should be between 10%-15% else you add water. In this case, the water hyacinth sample were below the expected range and could be regarded to as an under wet waste due to the large amount of water content it had. Water was therefore added in a ratio of 1:1 to avoid overfilling the digester. The water added isn't for the purpose of dilution but to allow easy movement of the bacteria throughout the waste for suitable digestion to occur.

A Volatile Solid Test was also done. This was to ascertain how much of the feedstock is biodegradable. The dry samples from the total solid test in section 3.2.1 (A) were used. They were blended into a powder that was placed in a furnace at 600°C after measuring it. After a period of 6 hours the sample was removed and the new weight measured. The remaining material was determined as the non-biodegradable and degradable portions (volatile solid). The results of the experiment are presented in Table 3.

Table 2. Total Solid Procedure Measurements

Sample name	Weight of container (g)	Weight of fresh water hyacinth sample (g)	Dry weight + container (g)	Total Solid (%)
WH^1	3.72	35.57	6.54	7.92
WH^2	3.75	35.57	6.43	7.53
WH^3	3.76	36.35	6.72	8.14
Average				7.86

Table 3. Volatile Solid Procedure Measurements

Weight of container (g)	Weight of sample (g)	Weight of ash + container (g)	Volatile solid (%)
26.53	2.48	26.83	12.10
22.32	1.39	22.47	10.79
20.09	1.68	20.28	11.31
			11.40

The volatile solid reflects the percentage of material that can be degraded to produce biogas. Most manure and sludge have volatile solids between 70-90% of the total solids. The remaining percentage accounts for inorganic materials in our feedstock that is non-biodegradable such as minerals, grit and salt which can dilute the energy content. Therefore the higher the total volatile solid the better the waste. The results indicated that water hyacinth samples were significantly bio degradable.

A PH Test was carried using a fresh sample and PH meter. The PH value derived was 5.85 for the sample. Optimum digestion occurs at a PH between 6.8 and 7.2 and our waste happens to be acidic as its PH is below 7.0. However after introducing our source of bacteria (cow dung), it was neutralized without the need of adding an expensive alkaline. The above tests basically prepared the sample for the biogas production process.

Biogas Production and Analysis. This involved a series of tests. The first part included determining optimum conditions for biogas production. Four different digestion set ups were run as shown in Table 1. Each set up was aimed at determining the biogas production performance under different conditions. Setup 1 had three biogas production samples i.e. Samples 1, 2 and 3 run under optimum conditions (Water hyacinth mixed with cow dung in a ratio 3:1 and the resultant mixed with water in a ratio of 1:1) under neutral PH, mesophilic conditions (35^{o}C), and co-digestion with cow dung as our source of bacteria. The objective was to check the biogas produced under the most optimum conditions with three samples run for confirmatory tests. Their digestion yield characteristics as shown in Figures 3 and 4.

Setup 2 had biogas production from sample 4, carried out at neutral PH, mesophilic conditions (35^{0}C) without co-digestion from cow dung. This was to determine how much variation exists between the quality and quantity of biogas generated from water hyacinth alone and water hyacinth under co-digestion with cow dung. Setup 3 had biogas

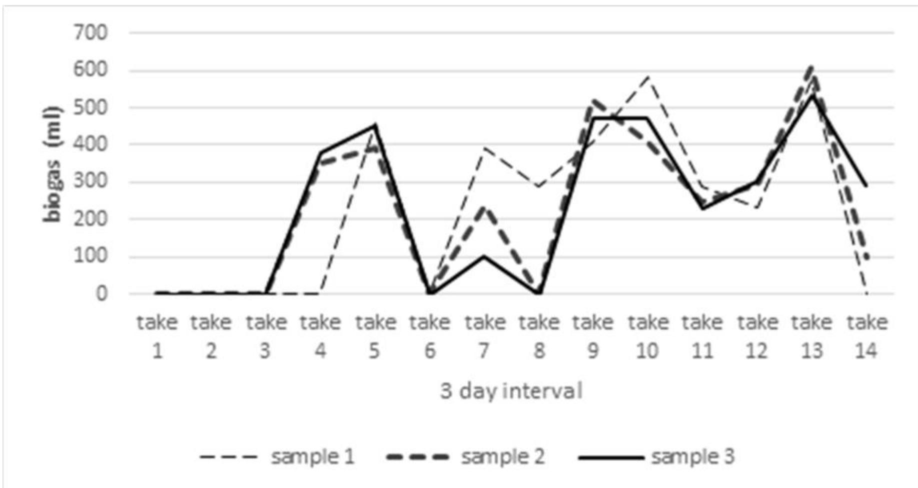

Figure 3. Biogas Production setup 1 (Bp samples 1, 2 & 3)

production from sample 5 run under similar conditions as those in setup 1 with the exception of the temperature. It was carried out under room temperatures to check the quality and quantity of biogas produced and how it varies from that produced under optimum temperature conditions. Comparatively, results for samples 1, 2, 3,4 and 5 is shown in Table 4 and Figure 5. Samples 1, 2 and 3 yielded the best results. This was attributed to the cow dung that had been added which is a highly proteinaceous waste; rich in amino acids as compared to using only water hyacinth.

The cow dung therefore boosts the calorific value of the feedstock. Sample 4 has low grade biogas that isn't combustible mainly because it was only water hyacinth used and would therefore need gas cleaning. Sample 5 emphasizes the need to carry out digestion at constant and suitable temperatures between 35°C and 40°C. These temperatures are suitable for methane forming bacteria to operate hence better quality gas with more methane and within a shorter retention time than at ambient temperature. This is because ambient temperatures are quite low for bacteria to act and are constantly varying.

Assessing period required to generate quality biogas. Another setup (no. 4) was established under the optimum conditions like setup 1. The purpose of this setup was to assess the quality of the methane produced. A reference sample was set up so as to monitor the methane increment with time as shown in Figure 6. This helps in determining around which time one can start to obtain biogas suitable for electricity generation. The gas produced was analysed after every 5 days.

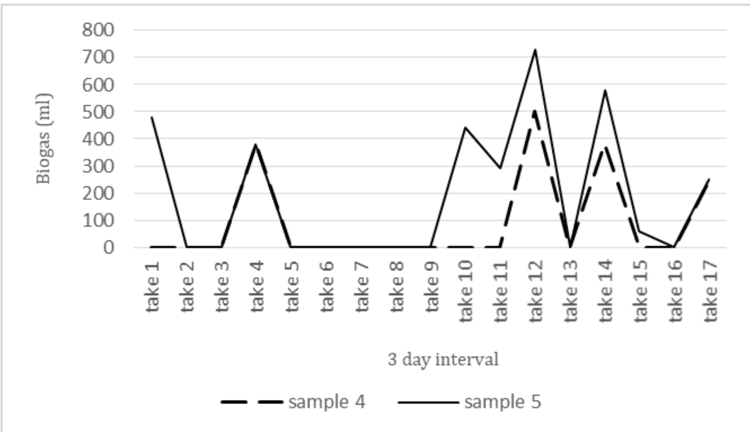

Figure 4. Biogas Production for setup 2 and 3 (Bp samples 4 and 5)

Table 4. Average values of methane content and volume of the gas produced)

Sample	Average Methane content (%)	Average Gas volume produced (Liters)	Mass of added water hyacinth
Sample 1, 2 and 3 (optimum conditions with cow dung)	60.1	3.215	200g
Sample 4 (under ambient temperature)	14	1.510	200g
Sample 5 (No cow dung added)	43	1.700	200g

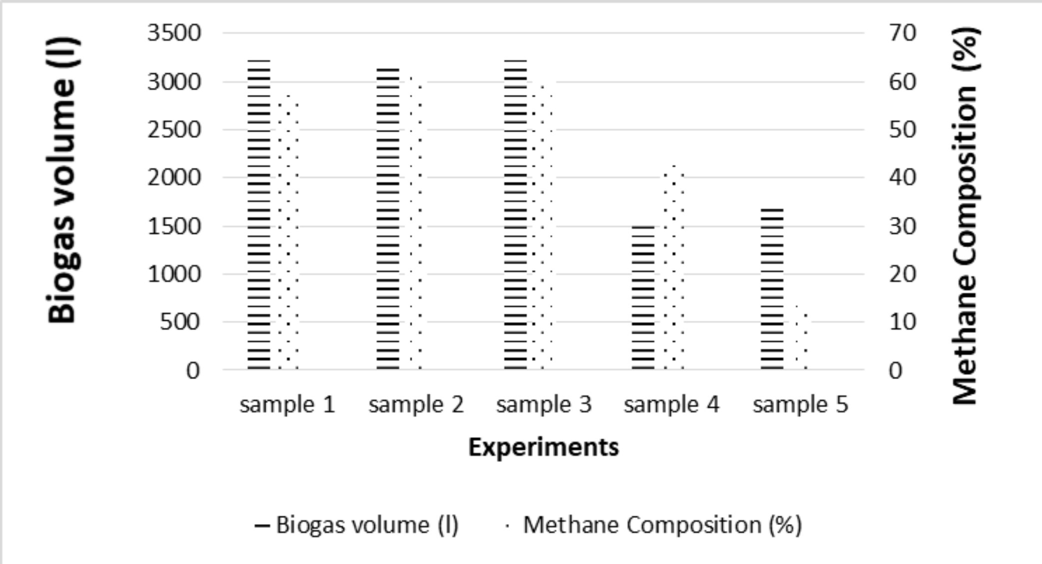

Figure 5. Comparison for all five samples

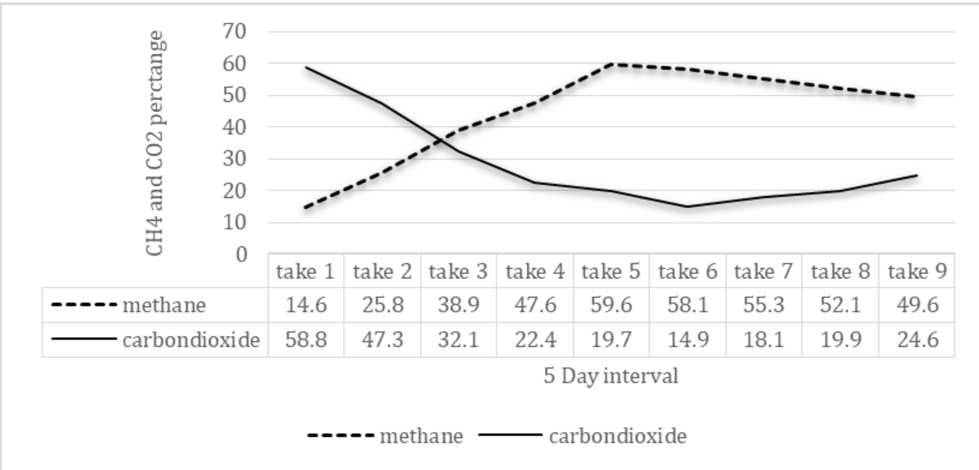

Figure 6. Time (days) taken to yield sufficient methane content

Figure 6 shows that methane production peaked at around day 25. Specific to usable biogas for electricity production, water hyacinth produces quality biogas after 20 days and stops after 30 days, under optimum conditions.

CONCLUSION

Given the biogas potential shown in the discussion above, water hyacinth can be a very suitable renewable energy source for Uganda. The research was based on one major case study area yet water hyacinth exists in other parts of Lake Victoria such as Port Bell, Gabba Landing site and many other places in vast number. If wholly exploited, it can contribute a significant amount of electrical energy that can be readily used to supply the communities in and around the shores of Lake Victoria. With a monthly energy generation of 23.9MWh, about 305 households can be supplied with such energy in Uganda.

ACKNOWLEDGEMENT

The funding for this research was provided by the Research and Education Agency.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

Eskom Uganda Limited, Monthly reports for period 2015-2017.

Frazier, J. 2018. Biogas Production from Water Hyacinth Blends, p. 8, 2014 https://a11.asmdc.org/article/frequently-asked-questions-water-hyacinth

Njogu, P., Kinyua, R., Muthoni, P. and Nemoto, Y. 2015. Biogas production using water hyacinth (*Eicchornia crassipes*) for electricity generatioin in Kenya. *Energy and Power Engineering* 7: 209-216.

Opande, G.O., Onyango, J.C. and Wagai, S.O., 2004. Lake Victoria: The water hyacinth (*Eichhornia crassipes* [MART.] SOLMS), its socio-economic effects, control measures and resurgence in the Winam gulf. *Limnologica-Ecology and Management of Inland Waters* 34 (1-2): 105-109.

Patil, J. H., MA Lourdu, A. R., Gavimath,C.C. and Hooli, V. R., 2011. *International Journal of Chemical Sciences and Applications* 2 (2): 148-155.

Ting, W. H. T., Tan, I. A. W., Salleh, S. F. and Wahab, N. A. 2018. Application of water hyacinth (*Eichhornia crassipes*) for phytoremediation of ammoniacal nitrogen: A review. *Journal of Water Processing Engineering* 22: 239-249.

Ukpai, P. A. and Nnabuchi, M. N 2012. Comparative study of biogas production from cowdung, cow pea and cassava peeling using 45 liters of biogas digester. *Advances in Applied Sciences Research* 3 (3): 1884-1869.

Wawire, N. W. 2004. The review of the impact of water hyacinth on Lake Victoria. Lake Victoria. Enviromental Management Project, Eldoret, Kenya.