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BIOGAS PRODUCTION FROM WATER HYACINTH BLENDS

Fadairo A.A.* and Fagbenle R.O.
*Author for correspondence
Department of Mechanical Engineering,
Obafemi Awolowo University
Ile Ife, Nigeria.
E-mail: bayofad4u@yahoo.com

ABSTRACT

This work studied the biogas generation potential of water hyacinth. This was with a view to determining the effects of blending cow dung and poultry droppings with water hyacinth on the yield of biogas. Samples of water hyacinth, cow-dung and poultry droppings were obtained from the Lagoon front of the University of Lagos Nigeria, an abattoir in Ile Ife Nigeria and the Teaching and Research Farm of the Obafemi Awolowo University Ile Ife Nigeria respectively. The sample of water hyacinth was subjected to some pretreatments before it was blended with cow-dung and poultry droppings in varying proportions and then digested in anaerobic digesters for a retention time of thirty days. The results showed that the water hyacinth blend with proportions of water hyacinth, cow dung and poultry droppings in the ratio of 2 : 2 : 1 respectively, produced the largest volume of biogas of 3.073 Litres per 2.5kg of the feedstock while water hyacinth alone which served as the control for the experiment produced the smallest volume of biogas of 0.931 Litres per kg of the feedstock. The result of the Gas Chromatography analysis revealed that the biogas had Methane (62.14%), Ammonia (0.44%), Carbon (IV) oxide (34.44%), Hydrogen sulphide (1.38%) and Carbon monoxide (0.44%). The study concluded that the biogas production from water hyacinth could be optimized by subjecting it to some pretreatments like blending with animal wastes.

INTRODUCTION

Fossil fuels currently provide the bulk of world's primary energy [1]. Since fossil fuels are nonrenewable natural resources and rate of its utilization exceeds the natural rate of production, an end point exists. There is thus a need for the development of new energy sources that will be more economically competitive [2,3,4]. For example, the world has gone through the wood age, the coal era, and will likely be done with the petroleum and natural age. Yet we still have wood and coal around but they are not economically competitive with oil and natural gas. The same will happen to oil and natural gas eventually when the rate of exploitation exceeds the rate at which it is generated underground. New and more economic sources of energy are constantly being developed and eventually the best will probably take over from the current oil and natural gas era.

Biomass has been defined as the natural biological storage of energy (solar) and other materials in complex organic substances primarily by gross photosynthesis [5]. The biomass resources of Nigeria are wood, forage grasses and shrubs, animal excretion, aquatic biomass and waste arising from forestry, agricultural, municipal and industrial activities [6].

Biogas is a flammable gas consisting of methane (54% – 70%), carbon (IV) Oxide (27% - 45%), Nitrogen (0.5% - 3%), Carbon (II) Oxide (0.1%), Oxygen (0.1%) and traces of hydrogen sulphide and water vapour [7]. It is generated by the anaerobic biodegradation of any organic waste such as grass, animal excrements, municipal sewage sludge, abattoir waste, paper waste, grain stalks, water weeds (water hyacinth, algae, duck weed, water lettuce etc.).

Biogas production consists of three biochemical process comprising hydrolysis, acetogenesis and methanogenesis [7].

$(C_6H_{10}O_5)_n + nH2O \rightarrow n(C_6H_{12}O_6)$ - Hydrolysis

$n(C_6H_{12}O_6) \rightarrow nCH_3COOH$ - Acetogenesis

$nCH_3COOH \rightarrow nCH_4 + CO_2$ - Methanogenesis

Biogas technology amongst other processes (including thermal, pyrolysis, combustion and gasification) has in recent times also been viewed as a very good source of sustainable waste treatment and management, as disposal of wastes has become a major problem especially in the large cities of many developing countries [8]. The effluent of this process is a residue rich in essential inorganicelements needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects on the environment [6]. Various wastes have been utilized for biogas production and they include animal wastes [9, 10, 11, 12], industrial wastes [13], food processing wastes [14, 15, 16], plant residues [17].

Water hyacinth, botanically called *Eichhornia crassipes,* is a floating, invasive plant commonly encountered as dense mats in freshwater habitats. Several features make it easy to be recognized. These features include glossy green leaves attached to thick, spongy roots always suspended in the water below the floating plant and attractive flowers when the plants are in bloom.

Water hyacinth is very difficult to eradicate by physical, chemical and biological means, and a substantial amount of effort is spent on their control annually throughout the world. It is also a sturdy specie. It causes blockage of irrigation channels affecting the flow of water to fields, it gets entangled with motorboat rotors, making fishing difficult and almost makes many riverine locationsinhabitable and inaccessible. This may have a large impact on the life of marginal farmers, increasing poverty in the less developed world. Thus developing harvesting and productive utilization energy technologies for this resource is important for riverine communities invaded by this plant.

MATERIALS AND METHOD

A large quantity of Fresh Water hyacinth was obtained from the Lagoon Front of the University of Lagos, Lagos State, Nigeria. This sample was sun-dried to reduce its moisture content. The dried sample of water hyacinth was then cut into small pieces to allow for more surface area to be acted upon by the micro-organisms that bring about the anaerobic bio-digestion.Water displacement method was used to collect the biogas produced while the daily ambient temperature was taken and recorded. The volume of daily yield of biogas was recorded and the composition of a sample of biogas produced was analyzed using Gas Chromatography. All data gathered were subjected to appropriate statistical analysis. The details of these procedures are presented below.

Raw Material Processing

The samples of fresh water hyacinth obtained as described earlier were packed in five sack bags of 0.0001-m thickness; the bags were sealed with a wire tie. They were then transported to Solar Energy Laboratory at the department of Mechanical Engineering of the Obafemi Awolowo University Ile Ife, where the research was carried out. Individual bags were emptied and the contents exposed to the atmospheric conditions before the commencement of preliminary laboratory studies.

Sample Preparation

Sample preparation is an important stage in the digestion of water hyacinth as has been demonstrated from previous researches which have shown that certain pretreatments carried out on water hyacinth before being digested would lead to higher yields of biogas [19].

The fresh water hyacinth obtained was sun-dried for a period of thirty (30) days to reduce its moisture content as shown in Plate 3.1. Following this, the dried sample was weighed to determine the reduction in its moisture content. This was then followed by the size reduction to about 0.02 m. The sample was then measured and then divided equally into 9 equal parts, each of which was later soaked in water for a period of 2 days to allow for partial decompositionbefore being loaded into the reactor.

The cow dung collected from an abattoir in the neighborhood was weighed using a 209 Ambrose Weighing Scale. The local abattoir unfortunately did not have any scientific data on the feed of the cows that produced the dung collected.

Wet Poultry droppings were obtained from the Poultry Unit of the Obafemi Awolowo University Teaching and Research Farm (OAUTRF). The weight of the quantity of droppings obtained was determined using a 209 Ambrose Weighing Scale. No scientific data on the feed of the poultry was available at the OAUTRF.

Plate 3.1: Dried Water hyacinth

ANAEROBIC DIGESTION

Nine laboratory-scale anaerobic digester setups were constructed for use in this research. Each digester setup had a digester with capacity of 0.015 m^3, one 0.0254 m gate valve, 0.0254 m internal diameter gas hose, 0.02032 m internal diameter water hose and two 0.004 m^3 containers. Two inlets were provided on the digester: One with a diameter of 0.127 m served as the inlet for the feedstock while the other of 0.0254 m diameter served as the outlet for the biogas produced and it was connected to the 0.0254 m gate valve which was used to control the flow of the gas from the digester. This valve was connected to 0.0254 m internal diameter hose gas pipe and immersed below the top of the water level contained in one of the 0.004 m^3 container while the other 0.02032 m water hose, which was above the top of water level, served as the collector of displaced water from the container containing water and delivered the water into the second empty 0.004 m^3 container. The nine systems were then set up and labeled A, B, C, D, E, F, G, H and I. Plates 3.2 and 3.3 show a typical digester setup and array of digester setups respectively.

Table 3.1 presents the compositions of each digester in different proportions of water hyacinth, cow dung and poultry droppings. Digester A served as the control for the research while W_h stands for water hyacinth, C_d stands for cow dung and P_d stands for poultry droppings.

Table 1: Compositions of each Digester

Digester	Proportions in Ratios ($W_h : C_d : P_d$)
A	1 : 0 : 0
B	1 : 1 : 0
C	1 : 0 : 1
D	1 : 1 : 1
E	2 : 1 : 0
F	2 : 0 : 1
G	2 : 1 : 1
H	2 : 2 : 1
I	2 : 1 : 2

After mixing the feedstocks thoroughly, all the digesters were diluted with water to reduce the percentage of solid in the substrate. Thus the volume occupied by water was about 41% of the volume of the 0.015 m^3 digester used for the research. The quantity of biogas from the digesters was measured by the downward displacement of water using graduated cylinder daily. Initial pH and temperature were measured directly from the fresh sample before it wassealed for the digestion process. Throughout the retention time, each digester was subjected to occasional shaking while ambient temperature and daily biogas production were measured and recorded.

Plate 3.2: A Typical Digester Setup

BIOGAS YIELD PROFILES

Figure 4.1 shows the biogas yield profiles of the digestion for the nine experimental setups, namely A to I. The biogas yield from digester H which has a substrate composition of water hyacinth, cow dung and poultry droppings in the ratio of 2:2:1 was found to be the highest with a value of 0.003073 m^3 while that of digester A which has water hyacinth alone as the substrate (control experiment) was found to be the lowest with a value of 0.000931 m^3. This could be explained by the fact that cow dung is a good source of biogas and assists in optimizing biogas production from water hyacinth.

The biogas yield from digester B, which has a substrate composition of water hyacinth, cow dung and poultry droppings in the ratio 1:1:0, that is, the poultry droppings was absent, was the second highest with a value of 0.002903 m^3. This also confirms that cow dung is a good blend to optimize biogas production from water hyacinth.

Meanwhile, it is worthy of note that biogas yields from digesters F and I with substrates compositions of water hyacinth, cow dung and poultry droppings in the ratios of 2:0:1 and 2:1:2 with values of 0.000922 m^3 and 0.001153 m^3 respectively were very low. These results were not expected as it is contrary to a well-proven opinion that poultry droppings area good biogas producer. It was found out that ammonium ions which are great inhibitors of biogas production were present in samples of the poultry droppings used for the experiment. These ammonium ions were suspected to have found their ways into the poultry droppings through the poultry feeds, vaccination or the disinfectant used to sanitize the surroundings of the poultry farm. But source of the ammonium ions was confirmed to be from the disinfectants, Quarternary Ammonium Compounds (commonly called QACs), used to sanitize the surroundings of the poultry at the Teaching and Research Farm of Obafemi Awolowo University where the poultry droppings sample used in this experiment was obtained.

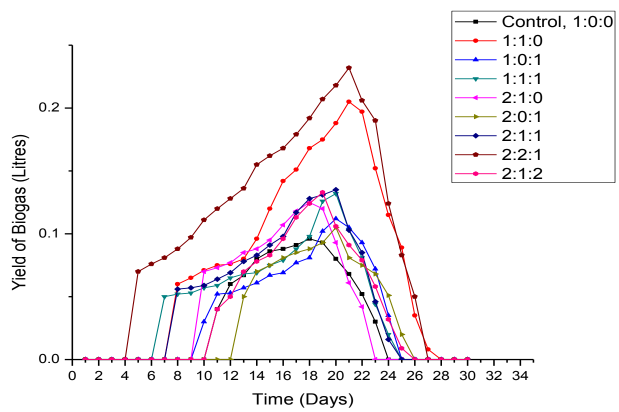


Figure 4.1(a) Biogas yield from the nine digesters

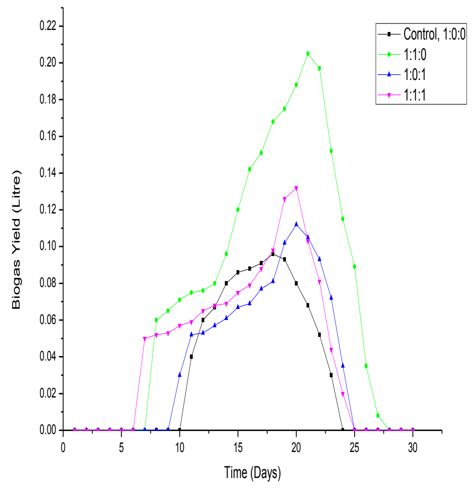


Figure 4.1(b) Biogas yield profiles for digesters A, B, C and D

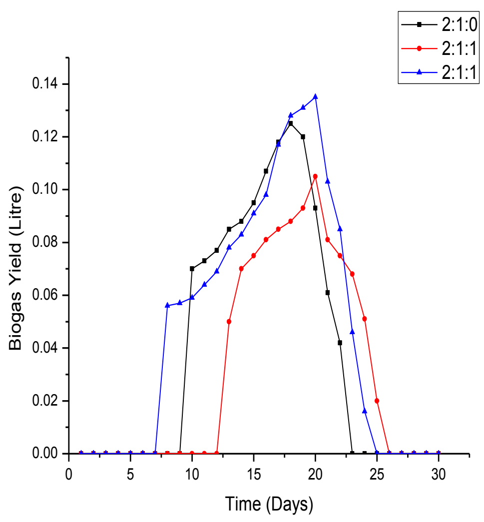


Figure 4.1(c) Biogas yield profiles for digesters E, F and G

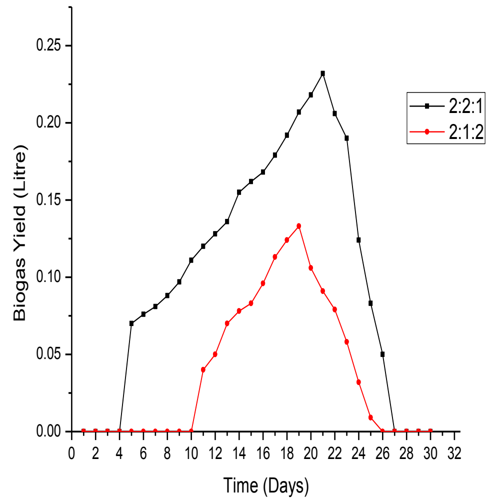


Figure 4.1(d) Biogas yield profiles for digesters H and I

STATISTICAL ANALYSIS

Effect of Blends on biogas yield

The single factor Analysis of Variance (ANOVA) was used to determine the significance of the effect of blends on the yield of biogas from water hyacinth at 95% confidence level. It gave an *F-value* of 6.45 which is far greater than the *P-value* of 0.0001. This shows that there is a significant effect of blend on the yield of biogas from water hyacinth.

Comparison of Means of biogas yield

Means of all biogas yield from each blend were compared using Duncan's Multiple Range test. The results showed that there is significant difference between the means of blend B which is 0.07560 and blend H which is 0.10243 while the means of biogas yield from the remaining blends, A, C, D, E, F, G and I, are not significantly different.

Table 4.2 Duncan's Multiple Range Test to compare Means of all biogas yield for each blend

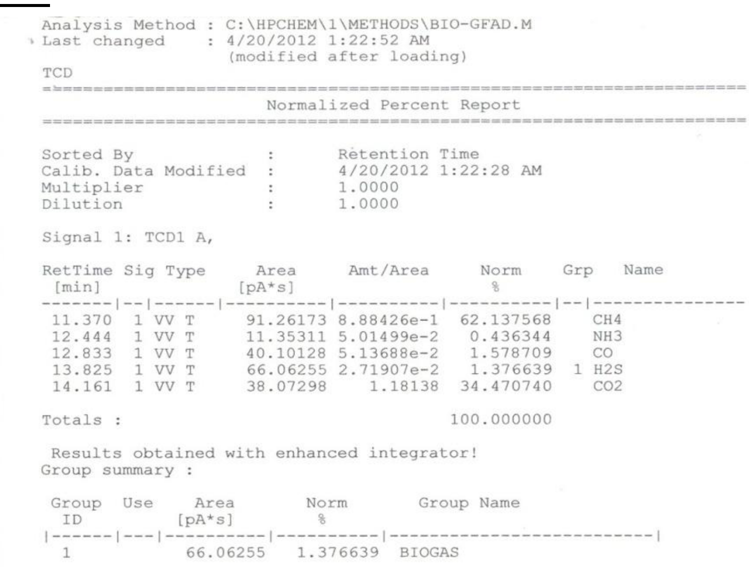
Blends	Means*
A	0.03103 C
B	0.07560 B
C	0.03553 C
D	0.04397 C
E	0.03847 C
F	0.03140 C
G	0.04720 C
H	0.10243 A
I	0.04143 C

*Mean values of biogas yield over 30 days
Mean with the same superscript are not significantly different

BIOGAS ANALYSIS

The chromatographic equipment is composed of the chromatographand a recorder for plotting chromatograms or a datastation for generation and evaluation of chromatograms. More attention was given digester H since it produced the highest yield of biogas. The biogas from digester H was then analysed using this equipment and the results are presented in figure 4.2.

It can be seen that methane composition is the highest at 62.14% while ammonia was the lowest at 0.44%. Others are carbon dioxide at 34.47%, carbon monoxide at 1.58%, and hydrogen sulphide at 1.38%.



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TCD
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Sorted By             :      Retention Time
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Multiplier            :      1.0000
Dilution              :      1.0000

Signal 1: TCD1 A,

RetTime Sig Type    Area      Amt/Area      Norm     Grp   Name
 [min]             [pA*s]                    %
-------|--|------|----------|----------|----------|--|---------------
 11.370  1 VV T    91.26173 8.88426e-1  62.137568      CH4
 12.444  1 VV T    11.35311 5.01499e-2   0.436344      NH3
 12.833  1 VV T    40.10128 5.13688e-2   1.578709      CO
 13.825  1 VV T    66.06255 2.71907e-2   1.376639  1 H2S
 14.161  1 VV T    38.07298    1.18138  34.470740      CO2

Totals :                               100.000000

 Results obtained with enhanced integrator!
Group summary :

 Group  Use    Area       Norm       Group Name
  ID          [pA*s]       %
|------|---|----------|----------|--------------------------|
  1           66.06255   1.376639  BIOGAS
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Figure 4.2 Gas Chromatography analysis

COMPOSITION OF BIOGAS PRODUCED

The composition of biogas produced is as depicted by the analysis carried out using a gas chromatography. Table 4.3 shows the constituent gases and their proportions.

Table 4.3: Constituent Gases and their Proportions

Constituent Gases	Proportion (%)
Methane, CH_4	62.137568
Ammonia, NH_3	0.436344
Carbon monoxide, CO	1.578709
Hydrogen sulphide, H_2S	1.376639
Carbon (IV) oxide, CO_2	34.470740

EVALUATION OF ENERGY GENERATING POTENTIAL OF WATER HYACINTH

An evaluation of energy generating potential of the biogas yield from digester H was carried out based on the quantity of methane produced as determined from the analysis carried out using gas chromatography. The calorific value of methane is given as 37 MJ/m^3 [20]. Using the percentage composition of methane in the biogas which is 62.14%, therefore, the calorific value of the biogas produced is calculated using the equation 4.1:

$$C_{biogas} = \% \, COMP_{methane} \times C_{methane} \quad 4.1$$

Where,

C_{biogas}= Calorific value of biogas produced

$\% \, COMP_{methane}$ = Percentage composition of methane in the biogas produced

$C_{methane}$= Calorific value of methane

Therefore, the calorific value of biogas produced is:

$$C_{biogas} = (37 \times 62.14\%) = 23 \, MJ/m^3$$

CONCLUSIONS

This work has investigated the biogas production from water hyacinth blended with cow dung and poultry droppings in varying proportions and the energy generating potential of water hyacinth blendsas well as the composition of the biogas produced. Based on the results obtained from the research and the laboratory tests carried out, the following conclusions are made.

The biogas production from anaerobic digestion of water hyacinth is optimized when blended with animal waste like cow dung and poultry droppings which will serve as catalysts for the process.

Water hyacinth as a source of energy will contribute to, and supplement the energy mix in the coastal areas of this country, especially when proper energy recovery method like the one in this research work is applied.

Water hyacinth could be a source of both energy, and hence economic development, of the coastal regions of Nigeria and other coastal areas of West Africa in particular and other developing countries. It is necessary to arouse private sector interest in the energy and economic potential of this otherwise troublesome weed for the coastal dwellers in many developing countries.

REFERENCES

[1] Goldembing, D. (2000). World Energy Assessment: World Energy and Challenge of Sustainability. UNDP/UN_DESA/, pp 31 -37.

[2] Bentley, R.W. (2002). Global Oil and gas depletion; an overview.Elsevier, New York.

[3] Cavallo, A.J. (2002). Predicting the peak in world oil production.Elsevier, New York.

[4] Kebede, D. (2004). Biomass energy for sustainable energy development. Symposium on renewable energies in Ethiopia (p. 79), Addis Ababa: Ethiopian rural energy development and promotion centre.

[5] Ryther, J.H. (1979). Biomass production from marine and fresh water plants. Proceedings of the third annual biomass energy systems conference, pp 13 – 23.

[6] Energy Commission of Nigeria (1998). Rural Renewable Energy Needs and Five Supply Technologies, pp 40 – 42.

[7] Ofofuele, A. U.; Uzodinma, E. O. and Onukwuli, O.D. (2009). Comparative study of the effect of different pretreatment methods on biogas yield from water hyacinth.*Nigerian Journal of Renewable Energy*, **6**, pp 43 – 45.

[8] Arvanitoyannis, I.;Kassaveti, A. andStefanatos, S. (2007a). Current and Potential uses of thermally treated Olive Oil waste. *International Journal of Food Science and Technology* **42**(7): 852 – 867.

[9] Nwagbo, E. E.; Dioha, I. J. and Gulma, M. A. (1991).Qualitative investigation of biogas from Cow and Donkey dung.*Nigerian Journal of Solar Energy*.**10**: 145 –149.

[10] Garba, B.; Zuru, A.A. and Sambo, A.S. (1996). Effect of slurry concentration on biogas production from cattle dung. *Nigerian Journal of Renewable Energy* **6**, pp 70 – 72.

[11] Zuru, A.A.;Saidu, H.; Odum, E.A. and Onuorah, O.A. (1998). A comparative study of biogas production from Horse, Goat and Sheep dung. *Nigerian Journal of Renewable Energy* **6** (1-2): 43 – 47.
[12] Itodo, I. andKucha, E. (1998). An empirical relationship for predicting biogas yield from Poultry waste slurry.*Nigerian Journal of Renewable Energy***l**(1-2): 31 – 37.
[13] Uzodinma, E.O.;Ofoefule, A.U.;Eze, J.I. And Onwuka, N.D. (2007). Biogas Production from blends of Agro-industrial wastes.*Trends Appl. Sci. Res.***2** (6): 554-558.
[14] Arvanitoyannis, I.;Kassaveti, A. andStefanatos, S. (2007b). Olive oil waste treatment: Acomparative and critical presentation of methods,advantages and disadvantages.*Crit. Rev. Food Sci. Nutr*.**47**(3): 187-229.
[15] Arvanitoyannis, I. and Ladas, D. (2008). Meat waste treatment methods and potential uses. *International Journal of Food Science and Technology*.**43** (3): 543 – 559.
[16] Arvanitoyannis, I. and Varzakas, T. (2008). Vegetable waste treatment:comparison and criticalpresentation of methodologies. *Crit. Rev. Food Sci. Nutr.***48**(3): 205-247.
[17] Ofoefule, A. U. and Uzodinma, E. O. (2008). Effect of Chemical and Biological treatment on Pre-decayed field grass (*Panicum maximum*) for biogas production. *Nigerian Journal of Solar Energy.***19**: 57 – 62.
[18] Center, T. D.; Dray,F. A.;Jubinsky, G. P. and Grodowitz, M. J. (1999). Biological control of water hyacinth under conditions of maintenance management:can herbicides and insects be integrated? Environmental Management23: 241-256.
[19] Conway, K. E. (1976). Evaluation of *Cercosporarodmanii* Conway as a biological control of water hyacinth. Phytopathology 66: 914 – 917.
[20] Fontenot, F.; Griling, D. and James, H. (1985). Water hyacinth in the Sudan-early results. *Biological Control news and Information***4**(3): 1