iJET EXPLORE International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 2, February, 2013

# Feasibility Study of Biogas Production from Water Hyacinth A Case of Lake Chivero – Harare, Zimbabwe

**[1]Kunatsa T , [2]Madiye L, [3]Chikuku T, [4]Shonhiwa C, [5]Musademba D**
[1, 5,] Lecturer, Department of Fuels & Energy, Chinhoyi University of Technology
[2,3,4,] Lecturers, Department of Mechanical Engineering ,University Of Zimbabwe

## ABSTRACT

Water hyacinth is considered as a noxious weed in many parts of the world as it grows very fast and depletes nutrient and oxygen rapidly from water bodies, adversely affecting flora and fauna. There have been instances of complete blockage of waterways by water hyacinth making fishing and recreation very difficult.

This paper investigated the possibility of producing biogas from Water Hyacinth (WH) taking Lake Chivero as a case study. It also focused on comparing the biogas output from dry and fresh water hyacinth. The wet mass of WH in Lake Chivero was found to be 197 400 tons/yr and the dry mass was 23 688 tons/yr. Experimental analysis gave a Water Hyacinth Total Solids of 10% and a Volatile Solids of 89.13%. Laboratory experiments showed that 1kg of WH yields 12.1 liters of biogas and a potential yield of 1681.08m$^3$/day which in turn yields 573 248.28 m$^3$/yr. The potential biogas obtainable would benefit 934 households and has an electrical generation potential of 87.56kW.The digester volume required was computed to be 10 419.90 m$^3$.

**Keywords:** *Water Hyacinth, methane, Fresh water, Lake Chivero*

## 1. INTRODUCTION

Energy consumption has increased steadily over the last century as the world population has grown and more countries have become industrialized. Biogas, a renewable biofuel is becoming increasingly important as a consequence of major concern for depleting oil reserves, rising crude oil prices and greenhouse effect. Water Hyacinth (*Eichhornia crassipes* Martius) is a monocotyledonous freshwater aquatic plant, belonging to the family Pontederiaceae, related to the lily family (Liliaceae) and is a native of Brazil and Equador region. It grows from a few inches to about a meter in height. The stem and leaves contain air filled sacs, which help them to stay afloat in water. Water hyacinth is considered as a noxious weed in many parts of the world as it grows very fast and depletes nutrient and oxygen rapidly from water bodies, adversely affecting flora and fauna. There have been instances of complete blockage of waterways by water hyacinth making fishing and recreation very difficult. Shoeb and Singh (2002) reported that under favorable conditions water hyacinth can achieve a growth rate of 17.5 metric tons per hectare per day.

There is a great discrepancy among policy makers, environmental agencies and research scientists on the way to control this invasive species and the practical benefits that can be obtained (Lu et al. 2008). There is a need for sustainability and a new perspective when it comes to managing this species, understanding and implementing their marketability as a newly found biofuel crop. Lake Chivero is a reservoir on the Manyame River. This water body is Harare's (the capital city of Zimbabwe) main water supply. The water is also used for irrigation purposes and commercial fishing. The lake and hinterland are protected as Lake Chivero Recreational Park. With the growing energy crisis supplemented by environmental concerns, biomethanation of Water hyacinth can serve as a biomass-to-energy generation alternative. Water hyacinth management problems and environmental concerns as well as the on-going successful shifting from non-conventional to renewable energy technologies has given an impulse for this research to focus on biogas production.

## 2. BIOGAS TECHNOLOGY SITUATION IN ZIMBABWE

The Government of Zimbabwe through the Ministry of Energy and Power Development has been promoting domestic biogas technology using animal waste. Nothing has been done with regards to using water hyacinth. Other organizations which complimented the efforts of the Ministry were Silveira House, Biomass Users Network and the Agricultural Engineering Institute among others. Common bio-digester designs which were promoted were the Chinese and the Indian type. However the Indian type was found to be more expensive than the Chinese because of the metal gas holder.

The failure rate was also noticed in China and India for the same reasons (Karekezi and Ranja, 1997) However in Nepal the implementation of the technology recorded success. According Karekezi and Ranja, (1997) the success was due to the commercial market based approach to the biogas programme. The biogas programme was multidisciplinary in approach involving sectors such as agriculture, health, finance and NGOs. There were also vigorous information and publicity programmes. Credit facilities and subsidies were given through Banks. *Table 2.1* shows methane production from sewage plants in some cities in Zimbabwe.

**Table 2. 1: Methane Production from Sewage Plants using Bio-digesters in Zimbabwe**

| City or Town | Sewage ($m^3$/day) | Biogas ($m^3$/day) | Methane ($m^3$/day) |
|---|---|---|---|
| Harare Crowborough | 940 | 23,500 | 8,500 |
| Harare Firle | 1,800 | 46,500 | 17,000 |
| Mutare | 30,000 | 1,107 | 554 |
| Masvingo | 16,800 | 621 | 311 |
| Bulawayo | 35,000 | 2,951 | 1,475 |

**Source: Zimbabwe Country Study (2001)**

## 3. METHODOLOGY

The following methods were used to for the feasibility study**:**

- Data collection and assessment of resource base(sight visits)
- sample collection
- sample analysis for total solids
- sample analysis for volatile solids
- anaerobic digestion for experimental procedure
- Potential gas yield calculations and digester sizing
- Economic analysis

## 4. RESULTS AND DISCUSSION

### 4.1 Water Hyacinth Resource Base Assessment and Quantification

In assessing Lake Chivero's resource base the following was found:

- Maximum width of the lake – 8km
- Surface area of lake – 2 632 hectares
- Maximum depth of Lake – 27m
- water hyacinth is estimated to be 300t/ha/yr on wet basis and 36t/ha/yr on dry basis (Twidell, 2006)
- Coverage of water hyacinth is estimated to be 25% of the lake

$$Wet\ Mass\ of\ water\ Hyacinth\ in\ Lake\ Chivero$$
$$= estimated\ wet\ weight\ per\ hactare\ x\ surface\ area\ x\ estimated\ \%\ coverage$$
$$= 300t/ha/yr\ x\ 2632\ ha\ x\ 0.25$$
$$= 197\ 400t/yr$$

Therefore the estimated total wet mass of water hyacinth in Lake Chivero is **197 400 tons**

$$Dry\ Mass\ of\ water\ Hyacinth\ = estimated\ dry\ weight\ per\ hactare\ x\ surface\ area\ x\ estimated\ \%\ coverage$$
$$= 36t/ha/yr\ x\ 2632\ ha\ x\ 0.25$$
$$= 23\ 688t/yr$$

### 4.2 Total and Volatile Solids

**Table 4. 1: Experimental results for Total and Volatile Solids**

| SAMPLES | A Leaves only | B Leaves + stem | C Stem only | D Roots only | E (mixed) Roots + Stem + leaves |
|---|---|---|---|---|---|
| **Total Solids (%)** | 15 | 10 | 7 | 11 | 7 |
| **Volatile Solids (%)** | 93.33 | 90 | 85.71 | 90.91 | 85.71 |

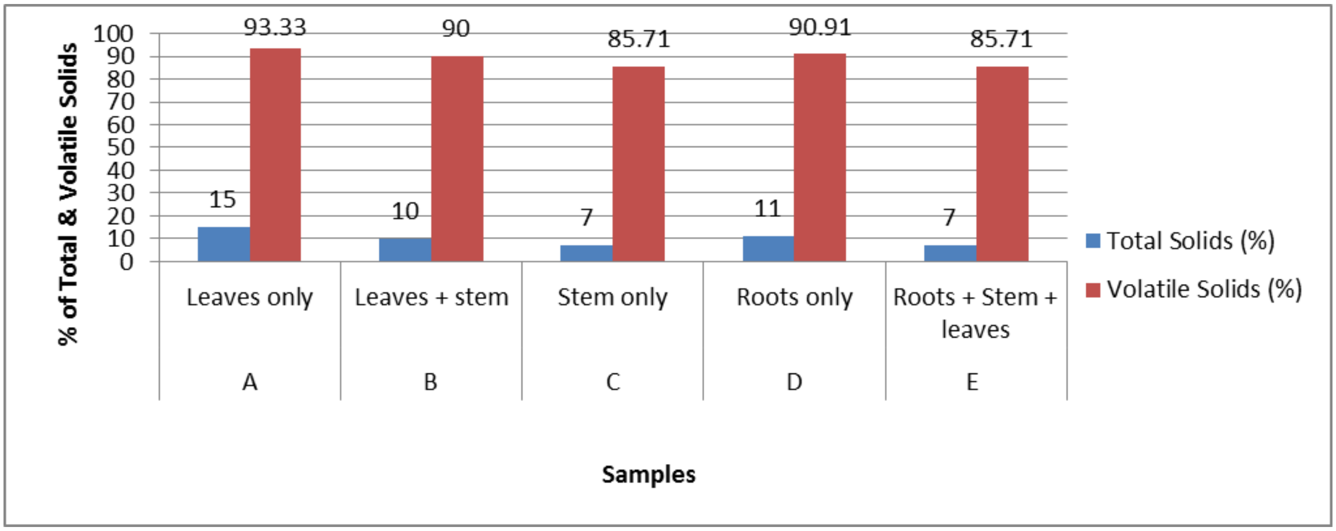


**Figure 4. 1: Pictorial view of experimental results for Total and Volatile Solids**

The Total Solids of water hyacinth was found to fall in the range of 85.71% – 93.33% and that of Volatile solids was found lying between 7% - 15%. The average values of TS and VS were computed and found to be 89.13% and 10% respectively.

## 4.3 Temperature Measurements

**Table 4. 1:Daily Temperature measurements**

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| FWH S1 (°C) | 31.1 | 31.6 | 31.7 | 30.3 | 31.9 | 29.8 | 32.2 | 30.3 | 31.7 | 30.8 | 30.6 | 31.9 | 32 | 32.2 | 29.9 | 31.8 |
| FWH S2 (°C) | 30.3 | 30.4 | 30.7 | 28.8 | 30.9 | 29.7 | 31.5 | 30.4 | 30.9 | 29.8 | 30 | 30.2 | 30.6 | 31.4 | 28.7 | 30.5 |
| FWH S3 (°C) | 30.3 | 31.2 | 31.3 | 30 | 31.4 | 29.8 | 30.6 | 30.4 | 31.1 | 28.6 | 30.3 | 30.4 | 30.9 | 31.1 | 29.6 | 30.1 |
| FWH daily ave(°C) | 30.6 | 31.1 | 31.2 | 29.7 | 31.4 | 29.8 | 31.4 | 30.4 | 31.2 | 29.7 | 30.3 | 30.8 | 31.2 | 31.6 | 29.4 | 30.8 |
| | | | | | | | | | | | | | | | | |
| DWH S1 (°C) | 29.3 | 28.9 | 32.1 | 30 | 31.1 | 29.2 | 30.2 | 30 | 32 | 30.6 | 30.9 | 31.6 | 31.4 | 31.1 | 29.5 | 30 |
| DWH S2 (°C) | 29.2 | 29.2 | 31.9 | 30.6 | 30.8 | 28.8 | 29.6 | 29.5 | 31.4 | 31.2 | 31.4 | 31.5 | 31.6 | 31.4 | 29.8 | 30.7 |
| DWH S3 (°C) | 29.5 | 29.4 | 31.7 | 31.4 | 31.7 | 29.3 | 30.3 | 29.9 | 30.9 | 30.4 | 30.4 | 30.1 | 30.6 | 30 | 29.4 | 29.9 |
| DWH daily ave (°C) | 29.3 | 29.2 | 31.9 | 30.7 | 31.2 | 29.1 | 30.0 | 29.8 | 31.4 | 30.7 | 30.9 | 31.1 | 31.2 | 30.8 | 29.6 | 30.2 |

The daily temperature fluctuations were generally the same for the Fresh Water Hyacinth (FWH) and Dry Water Hyacinth (DWH) samples. The minimum temperature recorded was $28.7^0$C and the maximum temperature reached was $32.2^0$C. The anaerobic digestion occurred in the mesophilic range and had a retention time of 15 days. This agrees with ISAT/GTZ (1999) who concluded that in tropical countries, unheated digesters are likely to be at average ground temperature between 20 and $30^0$C.

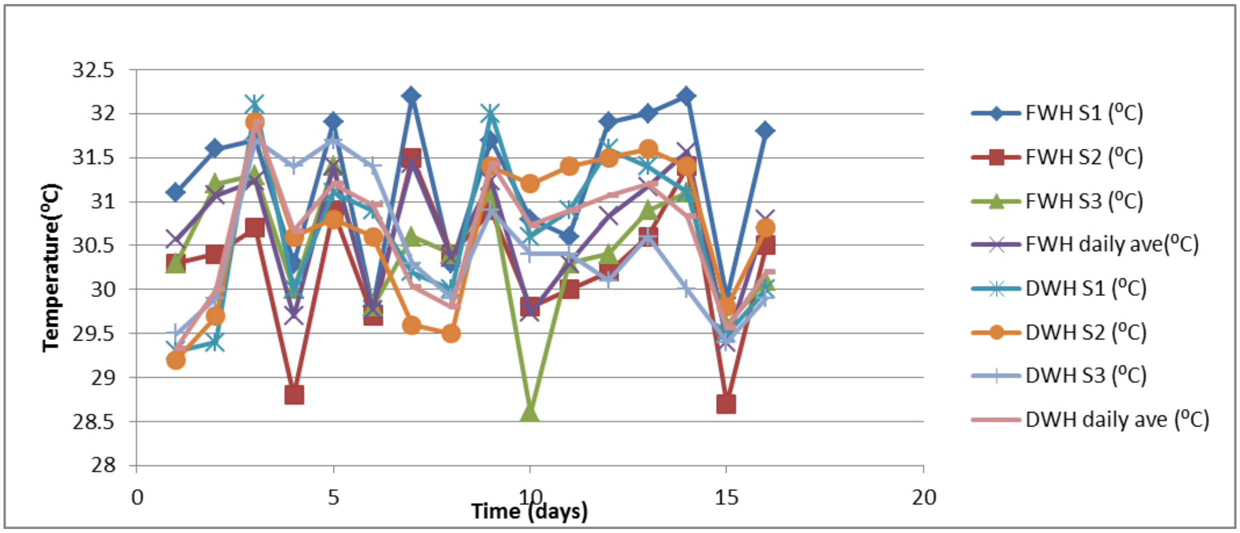


**Figure 4. 2: DailyTemperature measurements**

## 4.4 pH Measurements

**Table 4. 2: Daily pH measurements**

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| FWH S1 | 6.6 | 6.5 | 6.1 | 5.7 | 4.3 | 4.5 | 6.1 | 6.8 | 7 | 7.1 | 7.6 | 8.7 | 8.5 | 8.9 | 8.9 | 8.9 |
| FWH S2 | 6.4 | 6.2 | 5.8 | 4.8 | 4.5 | 4.7 | 5.9 | 6.6 | 6.9 | 7.2 | 7.8 | 8.4 | 8.6 | 8.6 | 8.7 | 8.8 |
| FWH S3 | 6.9 | 6.3 | 5.6 | 5.3 | 5.1 | 5.1 | 6.4 | 6.4 | 6.6 | 6.9 | 7.5 | 7.9 | 8.2 | 8.3 | 8.3 | 8.4 |
| FWH daily ave pH | 6.6 | 6.3 | 5.8 | 5.3 | 4.6 | 4.8 | 6.1 | 6.6 | 6.8 | 7.1 | 7.6 | 8.3 | 8.4 | 8.6 | 8.6 | 8.7 |
| | | | | | | | | | | | | | | | | |
| DWH S1 | 6.2 | 6.1 | 5.6 | 4.9 | 4.5 | 4.9 | 5.7 | 6.9 | 7.4 | 7.7 | 7.9 | 8.3 | 8.3 | 8.4 | 8.4 | 8.5 |
| DWH S2 | 6.5 | 6.3 | 5.9 | 5.3 | 5.1 | 5.4 | 6 | 7 | 7.2 | 7.5 | 7.5 | 8 | 8.2 | 8.6 | 8.6 | 8.8 |
| DWH S3 | 6.4 | 6.2 | 5.6 | 5.1 | 4.8 | 5.9 | 6.6 | 7.1 | 7.3 | 7.6 | 7.8 | 8 | 8.6 | 8.5 | 8.7 | 8.7 |
| DWH daily ave pH | 6.4 | 6.2 | 5.7 | 5.1 | 4.8 | 5.4 | 6.1 | 7.0 | 7.3 | 7.6 | 7.7 | 8.1 | 8.4 | 8.5 | 8.6 | 8.7 |

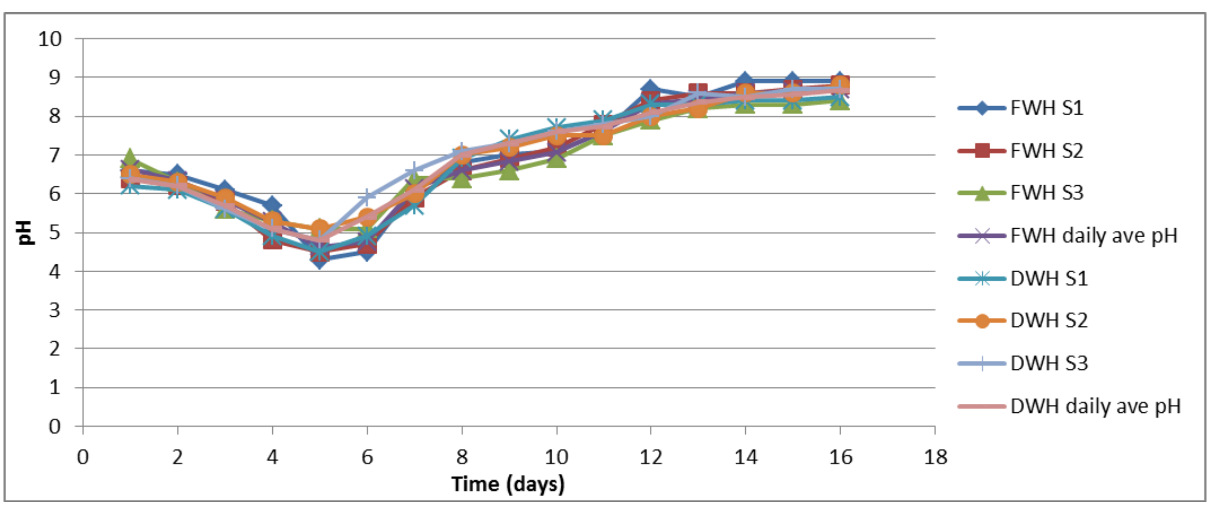

**Figure 4. 3: Daily pH measurements**

The initial pH were input between 6.2 and 6.9, this agrees with Mahanta et al (2004) who indicated that pH range of input mixture into the digester should be between 6.25 and 7.50 for most methanogenic bacteria to function. Overaly in all the experiments pH decreased from the beginning of the experiment upto the 5th and 6th days when it started to increase again. During the initial digestion phase, low biogas production quantities and pH decrease were observed for all the FWH and DWH samples. The acid forming bacteria produced VFAs at the initial stages of digestion resulting in a decline in pH and diminishing growth of methanogenic bacteria making them inactive. (Verma, 2002). During the 5th day NaOH was added to increase the pH of the samples to within the optimum range for methanogens. There was an increase in pH from about 4.5 to about 8.8 in all reactors from the 6th upto the 15th day when it started to decrease again.

## 4.5 Biogas Production Results

### 4.5.1 Fresh Water Hyacinth Biogas Production Results

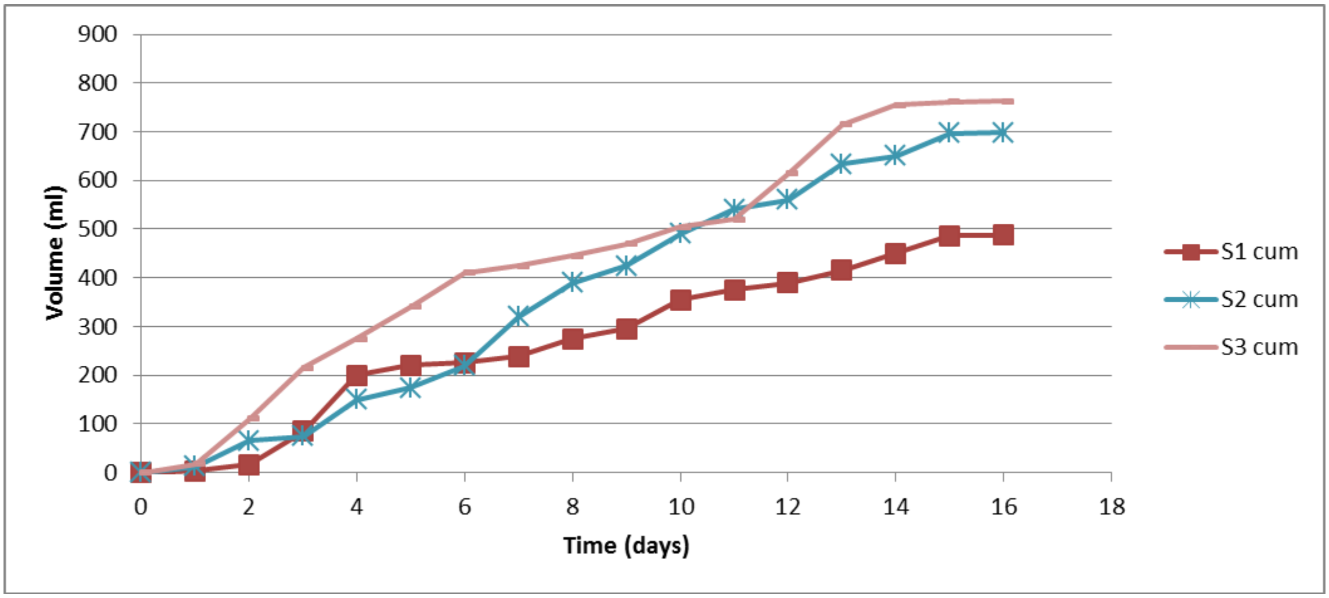


**Figure 4. 4: Fresh water hyacinth cumulative biogas production**

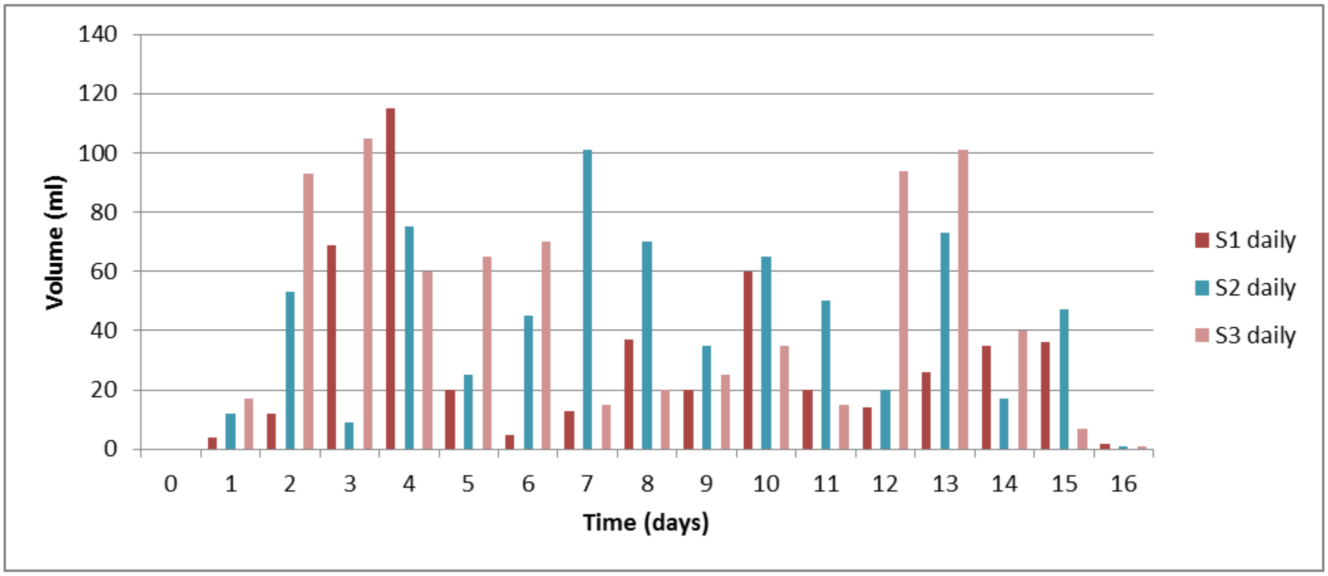

Figure 4. 5: Fresh water hyacinth daily biogas production

### 4.5.2 Dry Water Hyacinth Biogas Production Results

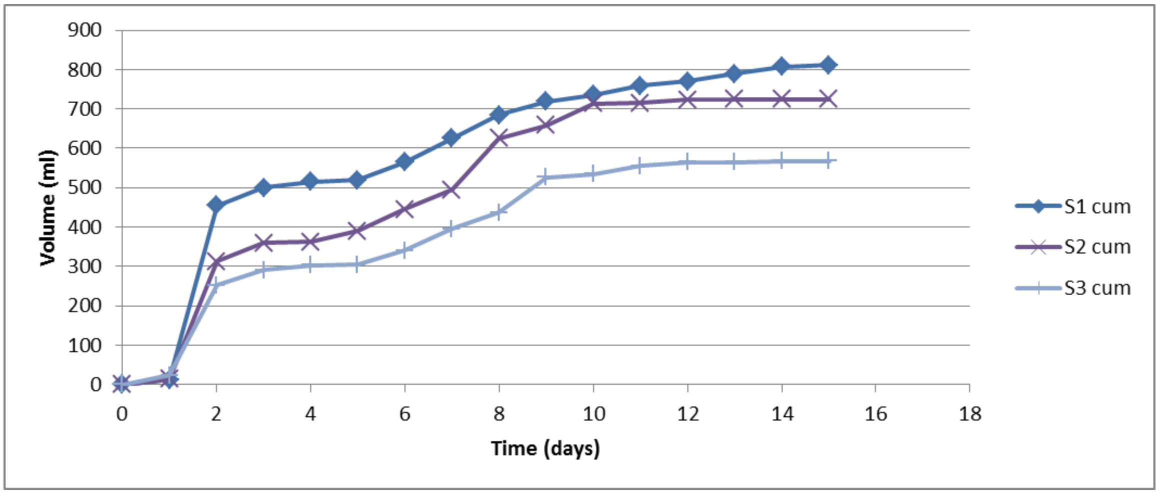


Figure 4. 6: Dry water hyacinth cumulative biogas production

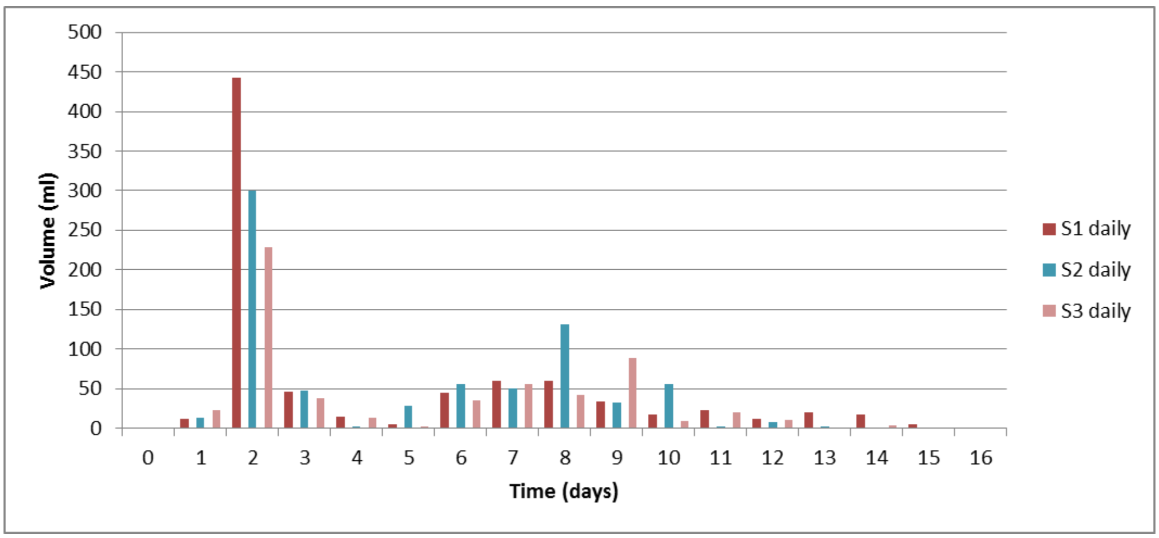


Figure 4. 7: Dry water hyacinth daily biogas production

### 4.5.3 Comparison of FWH and DWH Biogas Production

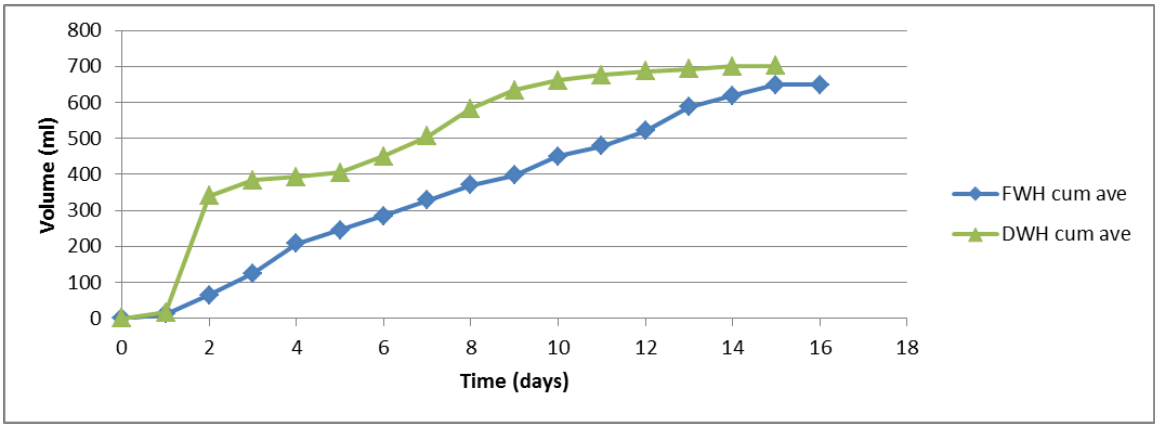


**Figure 4. 8: Fresh & Dry Water Hyacinth cumulative biogas production comparison**

It can be deduced from the cumulative curve that dry water hyacinth yields more biogas and that the rate of biogas production is higher with the same.

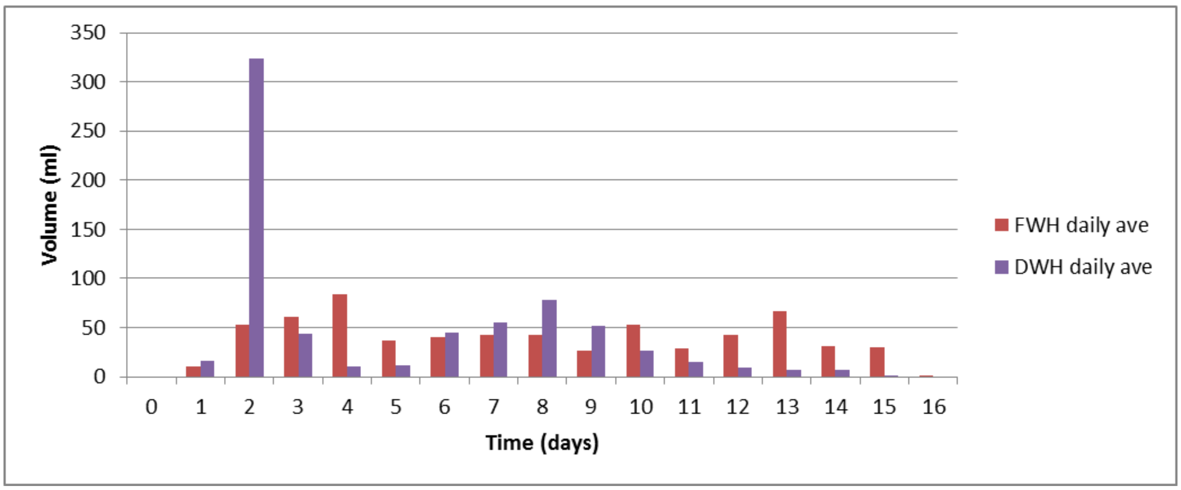


**Figure 4. 9: Daily FWH & DWH biogas production comparison**

### 4.5.4 Discussion of Biogas Production Results

Biogas production rate was slow for the first few days. During the initial digestion phase, low biogas production quantities were noted due to a decrease in pH for all the FWH and DWH samples. The acid forming bacteria produced VFAs at the initial stages of digestion resulting in a decline in pH and diminishing growth of methanogenic bacteria making them inactive and consequently inhibiting biogas production. (Verma,2002). The rate of biogas production started to increase proportionally up until the 15$^{th}$ day. Cumulative biogas production for the 15 day retention time was 650ml and 702ml for FWH and DWH respectively. From the experiments carried out it was found out that the rate of biogas production was higher with DWH and that the quantity of biogas was higher with the same and hence the researcher worked with DWH in the sections which follow.

## 4.6 Annual Biogas Yield Determination from Dry Water Hyacinth

58g DWH = 702ml

1000g = x

$$x = \frac{1000}{58} x\ 702$$

x = 12103.45ml

**1kg of DWH yields 12. 1 liters of biogas**

### 4.6.1 Correcting Gas Measurements Under Standard Temperature and Pressure Conditions

The barometric pressure reading was 1013.29 mbar and measured ambient temperature was 30$^{0}$C

Using the following formula

$$V_{STP} = V_M \frac{T_S \times P_M}{T_M \times P_S}$$

Where : $V_{STP}$ – Volume at standard temperature and pressure

$V_M$ – Measured volume
$T_S$ – Standard temperature
$T_M$ – Measured ambient temperature
$P_M$ – Measured pressure
$P_S$ – Standard pressure.

Standard pressure = 1013.25 mbar

Standard temperature = 297 K

$$V_{STP} = 0.0121 * \frac{297 \times 1013.29}{303 \times 1013.25}$$

**$V_{STP}$ = 0.01186m$^3$ = 11.86 litres of biogas per kg**

DWH biogas yield =12.1 ltrs per kg for a retention time of 15 days. Assuming that the digester is to be fed twice per month and that 2 days are needed for feeding per month

The digestion days in a year = 365 - (2*12) = 341 days and

The DWH biogas yield per day = $\frac{12.1\ x\ 2\ x\ 23\ 688\ x\ 1000}{1000\ x\ 341}$

DWH biogas yield = 1 681.08m$^3$/day

Biogas yield per year = 1 681.08 *341

**DWH biogas yield = 573 248.28 m$^3$/yr**

## 4.7 Electrical Power Generation Potential

1m$^3$ of biogas is equivalent to 1.25kWh of electricity (Alwis, A 2001),

Electricity generation Potential = 1 681.08*1.25 = 2 101.35kWh/day

Taking a day to have 24 hrs, Electricity Generation Potential = 2 101.35/24 = **87.56kW**

## 4.8 Determination of Households to Benefit from Biogas

**Table 4. 3: Households to benefit from biogas output**

| Total biogas gas output | Gas requirement per household | Number of households to benefit |
|---|---|---|
| 1 681.08m$^3$/day | Cooking (0.2m$^3$ per meal *3 meals) =0.6m$^3$<br>Lighting (0.1m$^3$ * 3hrs * 4 lamps) = 1.2m$^3$<br>Total gas requirement = 1.8m$^3$/day | $\frac{1681.08}{1.8} = 934$ |

## 4.9 Biogas Digester Sizing

The slurry to be fed into a digester has to have a total solids content of between 8-10% (Jagadish et al, 2012)

Digester volume, $V_d = S_d * R_t$

$S_d = (kg/yr)/(341\ days/yr)$ and $R_t$ = 15 days

$V_d = \frac{23\ 688 * 1000}{341} * 15$

$V_d$ = 1 041 994.135 kg/day

Assuming density of slurry is equal to density of water;

$V_d = \frac{1\ 041\ 994.135}{1000}$

$V_d$ = 1 041.99 m$^3$

Taking the $V_d$ calculated above to represent the solid water hyacinth which is 10% of the slurry, then amount of water to be added = 90/10 * 1 041.99 m$^3$ = 9 377.91m$^3$

The total volume of the digester = 1 041.99 m$^3$ + 9 377.91m$^3$ = 10 419.90 m$^3$

**The digester volume required is 10 419.90 m$^3$**

The appropriate digester to be used would be a fixed dome digester mainly due to its many advantages

## 4.10 Summary of Results

- Wet mass of WH in Lake Chivero is 197 400 tons/yr
- Dry mass of WH in Lake Chivero is 23 688 tons/yr
- Average Water Hyacinth TS = 10%
- Average Water Hyacinth VS = 89.13%
- 1kg of DWH yields 12. 1 liters of biogas
- Biogas yield = 1 681.08m$^3$/day

- 934 households can benefit from Lake Chivero's daily potential biogas yield
- Biogas yield = 573 248.28 $m^3/yr$
- The digester volume required is 10 419.90 $m^3$

**Table 4. 1: Summary of economic analysis**

| | **Biogas Option** | **Electricity Option** |
|---|---|---|
| Initial Investiment ($I_o$) | $2 383 980.00 | $2 418 980.00 |
| Annual Benefits | $1 621 117.45 | $1 019 206.76 |
| Annual costs | $151 878.60 | $155 578.60 |
| Cash Flow | $1 469 238.85 | $863 628.16 |
| Net Present Value (NPV) | $7 621 536.57 | $3 462 327.77 |
| Payback Period, $t_{PB}$ | 1 yr 11 months | 3 yrs 7 months |
| Internal Rate of Return (IRR) | 61.59% | 35.33% |

## 5. CONCLUSION

Biogas can be produced from Water Hyacinth. Water Hyacinth proves to be a promising renewable source of energy in the form of biogas. Daily biogas obtainable from Lake Chivero's Water Hyacinth is 1 681.08$m^3$. The rate of production will depend on many factors including the temperature, pH, degree of feedstock dryness among others. It was found through laboratory experiments that the rate of biogas production as well as the quantity of biogas is higher upon using dry water hyacinth as compared to fresh water hyacinth. 1kg of DWH yields 12.1 litres of biogas while FWH can only produce 1.28 litres per kg. Therefore the water hyacinth should be dried before use and inoculation with cow rumen contents or cow dung will increase biogas rate of production and ultimate yield.

The biogas can be used in the household for heating, cooking and lighting using domestic biogas stoves and lamps. 934 households are able to benefit in utilizing the biogas for heating, cooking and lighting from the 1 681.08$m^3$ daily gas production from water hyacinth. Electricity can be generated using Internal Combustion engines. Lake Chivero's Water Hyacinth is has the potential to generate 87.56kW of electricity. Table 6.1 below shows that the project is economically viable.

## 6. RECOMMENDATIONS

- This study recommends the Natural Resources and Environment sector, Parks and Wildlife Management sector, Zimbabwe National Water Authority and Municipality of Harare to venture into biogas production using water hyacinth
- Incorporation of Water hyacinth bio-digestion with existing bio-digester Infrastructure at Crowborough and Firle sewage treatment plants is recommended
- Municipality of Harare is recommended to get involved in the transportation of Water hyacinth since it has some contribution towards untreated waste-water effluents which aid water hyacinth growth

## 7. RECOMMENDATIONS FOR FURTHER STUDY

The following aspects can be taken as recommendations for further study of biogas production from water hyacinth

- Co-digestion of water hyacinth and other animal residues with the likes cow dung and pig manure is recommended in order to optimize the rate of biogas production
- It is hereby recommended that some further work be done in characterizing the biogas produced from water hyacinth by means of a Gas Chromatograph machine

The authors further recommends that since methanogenesis is sensitive to temperature fluctuations, effective insulation should be done during the digestion process

## REFERENCES


[1] Alwis, A de (2001), Study on the Potential of Biogas in Sri Lanka, ITDG South Asia

[2] ISAT/GTZ; Biogas Digest Volume I - Biogas Basics. 1999

[3] Lu JB, Fu ZH, Yin ZZ (2008) Performance of a water hyacinth (*Eichhornia crassipes*) system in the treatment of wastewater from a duck farm and the effects of using water hyacinth as duck feed.

[4] Shoeb F, Singh HJ(2002) Kinetic studies of biogas evolved from water hyacinth 2nd International Symposium on New Technologies for Environmental Monitoring and Agro – Applications pp 138

[5] Steffen R. Szolar O, Braun R. (2000) Feedstock for anaerobic digestion. Anaerobic Digestion,making energy and solving modern waste problem, AD-Nett report.

[6] Szczeck MM (1999). Suppressiveness of vermicompost against fusarium wilt of tomato. J. Phytopathol. Phytopathologische Zeitschrift 47: 155–161.

[7] Tesfaye Negussie (2007) Study on anaerobic digestion of chat wastes MSc Thesis, Addis Ababa University pp-28.

[8] Twidell & Weir, 2006, Renewable Energy Resources