Available online at www.ejournals.uofk.edu

U of KEJ Vol. 8 Issue 1 pp. 1-7 (February 2018)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Biogas Production from Water Hyacinth

Adil Abdelwahab Sharawi[1], Tagwa Basheer Ahmed [2], Zakaria Anwar Zakaria[3]

[1, 3] Department of Electrical Engineering,
[2]Department of Chemical Engineering,
Faculty of Engineering and technical studies
Elimam Elmahadi University, Kosti, Sudan
(E-mail: shash2022@gmail.com), (E-mail: Zakariaaz@gmail.com)

Abstract: The main objective of paper the conversion of the Water Hyacinth into a clean energy that can be exploited widely by a process of fermenting inside ferment devices. Three laboratory scale digesters were designed with different Water Hyacinth samples mixed with , water and Catalyst, the first model contains a green sample, the second sample was dried and the third was mixed green and dry with concentration of (34%, 18% and,24%), respectively. After ten days of fermentation the research showed that, the greater production of biogas was in the first digester (A). The second production was from digester (C), which contains the green and dry sample. The last one was digester (B) which contains the dry sample only with total volumes of (162509.71, 139273.12, 91540.35) cubic centimetres, respectively. The research shows that the green sample is the best in terms of the amount of gas produced.

Keywords: *Water Hyacinth, Fermentation, Digester, Clean Energy, Biogas.*

I. INTRODUCTION

Water Hyacinth is a vegetal plant, floating on the surface of the water and consists of a number of stems and has a wide green leaves accompanied by violet flower. This plant floats using the bulbs. The Water Hyacinth is collected in twisted groups, but some time separates them from each other to form a parallel plant. Water Hyacinth cause ecological and economic problem by impeding navigation and fishing activities, clogging irrigation systems and by creating a chronic shortage of dissolved oxygen harmful to fauna and the flora .[1]

Health care workers emphasize that, the impact of this plant on human and animal hygiene came as a result of its accumulation which became as a centre of germs and insects that transmit diseases such as mosquitoes, which transmit dysentery besides germs that cause yellow fever. Furthermore it constitutes a suitable environment for harboring snakes and crocodiles [2].

The Biomass represents the most important tool of exploiting solar energy in the ground, each plant absorbs the solar energy by means of photosynthesis to get use of it in the process of its growth as well as in producing Gas and Alcohol which can be used as sources of energy [3].

Digester is a device for producing biogas, the fermentation process occurs when the grasses and wastes are mingled with some water and put into the device. The decomposition of the grasses and wastes are undergone under specific conditions, inside the digester as a result the biogas is produced. This anaerobic decomposition will produce biogas [4].

Biogas is a naturally occurring mixture of (60% to 70%) methane and (30% to 40%) CO_2 with some H_2S. (Hydrogen Sulphide), where methane gas (CH_4) is the most important component of the biogas production. Biogas and methane gas can be used for many purposes especially in household [5].

2. WATER HYACINTH

Water Hyacinth (WH) is a free-floating perennial aquatic plant (or hydrophyte) native to tropical and subtropical in South America .With broad, thick, glossy, ovate leaves, Water Hyacinth may rise above the surface of the water as much as one meter in height figurer (1).

Fig. 1. Water Hyacinth in White Nile

The leaves are 10-20cm long, and float above the water surface. They have long stalks, spongy and bulbous. The feathery, freely hanging roots are purple-black. An erect stalk supports a single spike of (8-15) conspicuously attractive flowers, mostly lavender to pink in colour with six petals. One of the fastest growing plants known, Water Hyacinth reproduces primarily by way of runners, which eventually form daughter plants. Each plant can produce thousands of seeds each year, and these seeds can remain viable for more than 28 years. Some water hyacinths were found to grow up to 2 to 5 meters a day in some sites in Southeast Asia. The common Water Hyacinth (EC) are vigorous growers known to double their population in two weeks [6].

3. CARBON and NITROGN RATIO

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material [7].

As a result, gas production will be low on the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_4), will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population [1].

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8. C/N ratios of some of the commonly used materials are presented in Table (1) [7].

Table 1. Carbon to Nitrogen Ratio of Some Organic Material

S.N	Raw materials	Carbon and nitrogen ratio
1	Water Hyacinth	25
2	Human excreta	8
3	Chicken dung	10
4	Goat dung	12
5	Pig dung	18
6	Sheep dung	19
7	Cow dung/buffalo dung	24
8	Duck dung	8
9	Elephant dung	43
10	Straw (maize)	60
11	Straw (rice)	70
12	Straw (wheat)	90
13	Sum dust	Above 200

4. TYPES OF DIGESTION PROCESS

There are two types of digestion process:

4.1 Anaerobic digestion process

Anaerobic digestion is a natural process in which bacteria break down organic matter in an oxygen-free environment to form biogas and digest ate. A broad range of organic inputs can be used including manure ,food waste, and sewage, although the composition is determined by the industry, whether it is agriculture ,industrial, wastewater treatment, or others.

Anaerobic digesters are utilized in many situations where industrial or agricultural operations produce a significant organic waste stream .In addition municipal solid waste (MSW) landfills produce landfill gas from natural decomposition of organic material in the waste that can be captured for use as an energy source [8].

4.2 Aerobic digestion process

It is a bacterial process occurring in the presence of oxygen. Bacteria rapidly consume organic matter and convert it into carbon dioxide, water and a range of lower molecular weight organic compounds. As there is no new supply of organic material, the activated sludge biota begin to die and are used as food by saprotrophic bacteria.

This stage of the process is known as endogenous respiration and it is process that reduces the solid concentration in the sludge. Aerobic digestion is typically used in an activated sludge treatment plant. Waste activated sludge and primary sludge are combined, where appropriate, And passed to a thickener where the solids content is increased. This substantially reduces the volume that is required to be treated in the digest [8].

4.3 Parameters of Anaerobic Digestion

The efficiency of anaerobic digestion is influenced by some critical parameters. Thus it is crucial that appropriate conditions for anaerobic microorganisms are provided. The growth and activity of anaerobic microorganisms is significantly positively influenced by conditions such as exclusion of oxygen, constant temperature, correct pH-value, nutrient supply, stirring intensity (for larger systems), as well as negatively influenced by presence and amount of inhibitors (e.g. ammonia). The methane bacteria are fastidious anaerobes, so that the entry of oxygen (including outside air) into the digestion process must be strictly avoided [8].

4.3.1 Temperature

The AD process can take place at one of several temperature ranges. These are normally divided into three temperature ranges: psychrophilic (below 25°C), mesophilic (25°C – 45°C), and thermophilic (45°C – 70°C). There is a direct relation between the process temperature and the speed of the reaction, and so the hydraulic retention time (HRT). The temperature stability is decisive for AD. Temperature in the digester should not be allowed to vary by more than one Celsius degree per hour, and preferably less. In practice, the operation temperature is chosen with consideration to the feedstock used and the necessary process temperature in hotter climates is controlled by shading, or by burying the digester underground. In colder climates the correct temperature is usually provided by floor or wall heating systems inside the digester, [8].

4.3.2 pH-Values and Optimum Intervals

The pH-value is the measure of acidity/alkalinity of a solution (and so of the substrate mixture, in the case of AD). The pH value of the AD substrate influences the growth of methanogenic microorganisms and affects the formation of some compounds of importance for the AD process (ammonia, sulphides, and organic acids). Experience shows that methane formation takes place within a relatively narrow pH interval, from about 5.5 to 8.5, with an optimum range between (7.0 - 8.0) for most methanogens. Figure (2) shows pH Test film,
Acidogenic microorganisms usually have lower value of optimum PH.

The optimum pH interval for mesophilic digestion is between 6.5 and 8.0. The pH value can be increased by ammonia, produced during degradation of proteins, or by the presence of ammonia in the feed stream, while the accumulation of VFA decreases the pH-value.

The pH value inside digesters depends on bicarbonate alkalinity concentrations in the liquid phase and carbon dioxide in the gas phase. If the digester content swings to being more base or acid, the buffer capacity counteracts these changes in pH, up to a certain level. When the buffer capacity of the system is exceeded, drastic changes in pH-values occur, completely inhibiting the AD process. For this reason, the pH-value is not recommended as a stand-alone process-monitoring parameter [8].

Fig. 2. PH Meter

4.3.3 Organic Load

The construction and operation of a biogas plant requires a combination of economic and technical considerations. Obtaining the maximum biogas yield, by complete digestion of the substrate, would require a very long retention time of the substrate inside the digester and so a correspondingly large digester size. In practice, the choice of system design (digester size and type) or of applicable retention time is always based on a compromise between getting the highest possible biogas yield and having justifiable plant economy. In this respect, the organic load is an important operational parameter, and it indicates how much organic dry matter can be fed into the digester, per volume and time unit, according to the equation below [8].

$$BR = m \times c \quad (1)$$

5. MATERIAL AND METHODS

5.1 Methodology

Three laboratory scale anaerobic digesters systems were designed with different raw materials, to address the best design and fed material.

The digester which was used, very simple and useful configuration to produce biogas and called batch feeding digester, and it used different raw materials of grasses through fermenting by anaerobic digestion process, the Nile grasses (grass from river Nile in White Nile state). The selected mixed raw in conjunction with best design then will be used to produce the gas in practical model.

5.2 Design of digesters systems

Batch digesters are operated by filling the reactor with slurry, letting the reactions that take place in the reactor proceed to completion, and then removing some or all of the contents of the reactor. This procedure is then repeated. Stirring may or may not be part of the operation of a batch reactor. Advantages of a batch reactor include: ease of operation, absence of mechanical mixing, and high removal efficiency of an individual contaminant. Kinetics in a batch reactor are similar to the kinetics in an ideal plug flow reactor, bio solids from one batch of operation may be used to seed the subsequent batch reaction with microbes [8].Three systems were designed and each system had two main parts, batch digester and gas holder, figure (3).

Fig. 3. Digesters Systems

5.3 Digester

The digester is about a 19.220 litre plastic barrel, at the top of the digester there are two parts, the first one is the outlet part with two flexible tubes, to control the flow of the gas there were many valves (outlet gas) link the treat system and the gasholder with the digester. The second was testing part which is a pipe sucks inside the digester about 25cm to take the readings like pH and temperature, Figure (3) .The digester was placed above the level of floating tank to prevent water from collection inside the joining tube between the digester and gasholder in the start-up .

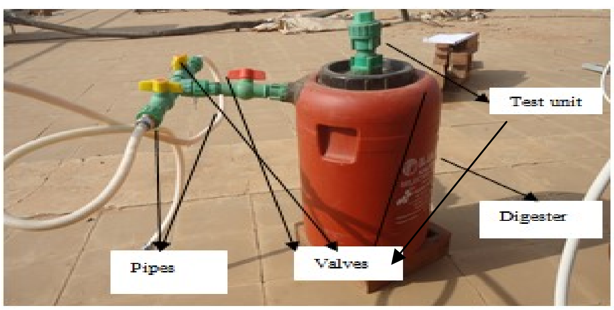

Fig. 4. The batch Digester.

5.4 Gasholder

The gasholder contain two barrels, the first is water tank and the second is floating tank (74.611 litre plastic barrel) Figure (5), the measurement tool is meter, to record gas production, figure (6). Figure (7) shows the floating tank dimensions.

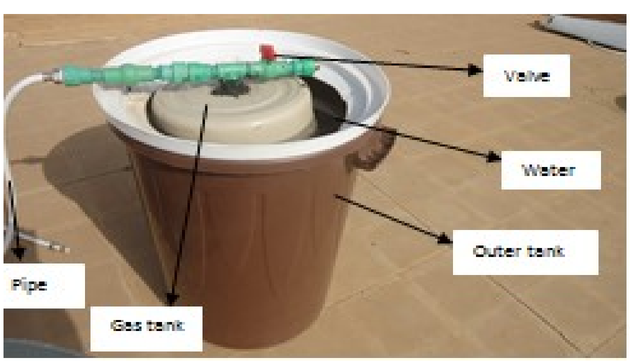

Fig. 5. Gas Holder

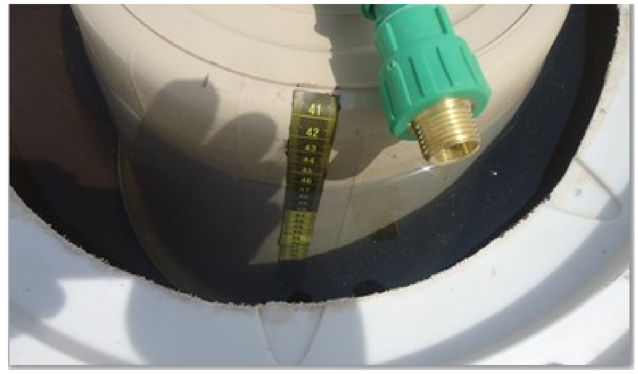

Fig. 6. Measurement Tool

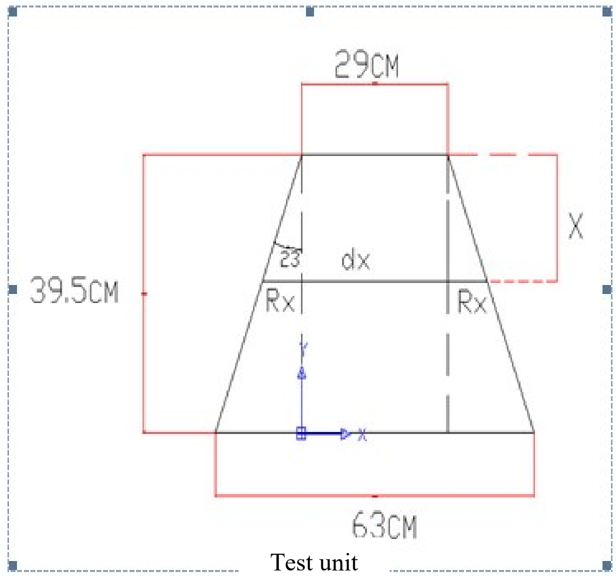

Fig.7. Floating Tank Dimensions

From figure (7) the volume of Biogas is computed as:

$$d\times = d_1 + 2r_\times \quad (2)$$

$$\tan(\theta) = r_\times/\times = (d_2 - d_1)/2L. \quad (3)$$

$$r_\times = ((d_2 - d_1)/2L)\,(\times). \quad (4)$$

$$d_\times = d1 + ((d_2 - d_1)/L)\,(\times). \quad (5)$$

$$V_\times = (\pi/4)\,((dx^2 + d_1^2)/2)\,(\times). \quad (6)$$

5.5 Pipes

There are two pipes in every system, the first one links the digester and the gasholder, and the second pipe is hold the biogas out the gasholder, the pipes are identical with length of 100 cm, inner diameter 0.9 cm, outer diameter 1.2cm, the inner cross section area is 0.636 cm^2, and the outer cross section area is 1.13 cm^2.

5.6 Control System

To control the flow of the gas, manual valves were used, there are two systems of valve, the first was designed to control the produced gas from the digester to either the gasholder or the treatment unit and the second one was design to control the produced gas after collection in the gasholder.

6. PROCESS OF ANAEROBIC DIGESTION

Biogas digestion is a complex, reduction process of a number of biochemical reactions occurring under anaerobic conditions. Under symbiotic effects of various anaerobic and relatively anaerobic bacteria, multi molecular organic substances are decomposed into simple, chemically stabilized compounds – mainly of methane and carbon dioxide [7].Generally, this process consists of liquefaction and hydrolysis of insoluble compounds and gasification of intermediate products. This is accompanied by a partial or complete mineralization and humification of organic substance [7].

6.1 Stages of Anaerobic Digestion

There are four chemical stages of anaerobic digestion

(A) Hydrolysis

Hydrolysis is theoretically the first step of anaerobic digestion, during which the complex organic matter (polymers) is decomposed into smaller units (mono), during hydrolysis ,polymers like carbohydrates, lipids, nucleic acids and proteins are converted into glucose ,glycerol, purines and pyridines, hydrolytic microorganisms excrete hydrolytic enzymes, converting biopolymers into simpler and soluble compounds.

A variety of microorganisms is involved in hydrolysis, which is carried out by exoenzymes ,produced by those microorganisms which decompose the undissolved particulate material.

The products resulted from hydrolysis are further decomposed by the microorganisms involved and used for their own metabolic processes [8].

$$(C_6H_{10}O_5)_n + n\,H_2O \xrightarrow[30-40°C]{Enzymes} n\,(C_6H_{12}O_6) \quad (7)$$

$$\text{Lipids} \xrightarrow{\text{Lipase}} \text{fatty acids} + \text{glycerol} \quad (8)$$

$$\text{Proteins} \xrightarrow{\text{Proteage}} \text{amino acids} \quad (9)$$

(B) Acidogenesis (Acidification Phase)

During this stage ,the acidifying bacteria convert water-soluble chemical Substances, including hydrolysis products to short-chain organic acids (formic, acetic, propionic, butyric ,pentanoic), alcohols (methanol, ethanol), aldehydes, carbon dioxide and hydrogen. From decomposition of proteins, amino acids and peptides arise, which may be a source of energy for aerobic microorganisms. Acidogenesis may be two-directional due to the effects of various populations of microorganisms. This process may be divided into two types' hydrogenation and dehydrogenation.

The basic pathway of transformations passes through acetates, CO_2 and H_2, whereas other acidogenesis products play an insignificant role. As a result of these transformations, methanogens may directly use the new products as substrates and energy source. Accumulation of electrons by compounds such as lactate, ethanol, propionate, butyrate, higher volatile fatty acids is the bacteria's response to an increase in hydrogen concentration in the solution. The new products may not be used directly by methanogenic bacteria and must be converted by obligatory bacteria producing hydrogen in the process called acetogenesis.

Among the products of acidogenesis, ammonia and hydrogen sulfide which give an intense unpleasant smell to this phase of the process should also be mentioned .The acid phase bacteria belonging to facultative anaerobes; use oxygen accidentally introduced into the process, creating favourable conditions for the development of obligatory anaerobes of the following genera: Pseudomonas ,Bacillus, Clostridium, Micrococcus or Flavobacterium [9].

$$C_6H_{12}O_6 \xrightarrow[30-70°C]{Bacteria} 2CH_3CH_2OH + 2CO_2 \quad (10)$$

$$3C_6H_{12}O_6 \xrightarrow{Propionibacter} 4C_2H_5COOH + 2CH_3COOH + 2CO_2 + 2H_2O \quad (11)$$

Acetogenesis:

In this process, the acetate bacteria including those of the genera of Syntrophomonas and Syntrophobacter convert the acid phase products into acetates and hydrogen which may be used by methanogenic bacteria.

Acetogenesis is a phase which depicts the efficiency of biogas production ,because approximately 70% of methane arises in the process of acetates reduction. Consequently, acetates are a key intermediate product of the process of methane digestion. In acetogenesis phase approximately 25% of acetates are formed and approximately 11% of hydrogen ,produced in the wastes degradation process [9].

$$CH_3CH_2OH \xrightarrow[(30-40)°C]{\text{acetate bacteria}} CH_3CHO + 2\,H+ \quad (12)$$

$$CH_3CHO + H_2O \xrightarrow[(30-40)°C]{\text{acetate bacteria}} CH_3COOH + 2\,H+ \quad (13)$$

(C) Methanogensis

This phase consists in the production of methane by methanogenic bacteria. Methane in this phase of the process is produced from substrates which are the products of previous phases, that is, acetic acid ,H_2, CO_2 and format and methanol, methylamine or dimethyl sulphide. Despite the fact that only few bacteria are capable to produce methane from acetic acid, a vast majority of CH_4 arising in the methane digestion process results from acetic acid conversions by heterotrophic methane bacteria [9].

Only 30% of methane produced in this process comes from

CO_2 reduction carried out by autotrophic methane bacteria . During this process H_2 is used up, which creates good.

Conditions for the development of acid bacteria which give rise to short-chain organic acids in acidification phase and consequently too low production of H_2 in acetogenic phase. A consequence of such conversions may be gas rich in CO_2, because only its insignificant part.

$$CH_3COOH \xrightarrow{\text{Methanogenic bacteria}} CH_4 + CO_2 \quad (14)$$

$$CO_2 + 4\,H_2 \xrightarrow{\text{Methanogenic bacteria}} CH_4 + 2\,H_2O \quad (15)$$

7. RESULTS AND DISCUSSION

7.1 Kinetics and cumulative production of biogas

The experiment took place from 17 September to 6 October 2017, after the 10 days of fermentation, the reading of the biogas production, temperature and pH were taken. The temperature inside the digester was about (30 - 40) ^oC and the atmosphere temperature is about (27- 40) Celsius degree. Where pH was in the range of 7-8.

Three samples were tested, the first sample was a green herb mixed with water at a concentration of 34% (digester A) figure (7), the second sample is dry grass with 18% concentration(digester B) , figure (8) and the third sample is a mixture of green and dry grass with 24% concentration (digester C) .Organic load from sample A (green sample) the mass of substrate fed is 1600 g, the concentration of organic fed equal 23 % and digester volume equal 19220 cm^3 then the value of organic load according to equation (3.5) equal to 0.01915 (g/cm^3).

from sample B (dry sample) the mass of substrate fed is 655.48g, the concentration of organic fed equal 8% and digester volume equal 19220 cm^3 then the value of organic load according to equation (1) equal 0.00273 (g/cm^3).

from sample C (dry sample + green sample) the mass of substrate fed is 1608.5g, the concentration of organic fed equal 19.13% and digester volume equal 19220 cm^3 then the value of organic load according to equation (1) equal to 0.016 (g/cm^3).

Fig. 8. Green Sample

Fig.9. Dry Sample

Fig.10. Reading of Temperature

Fig.11. Reading of PH

Table 3. Kinetics Production of Biogas for the Three Digesters

Day	V (cm^3) digester A	V (cm^3) digester B	V (cm^3) digester C
1	3829.10	2974.38	4731.75
2	5684.09	3829.10	7209.57
3	8856.66	5684.09	8072.5
4	13888.26	7209.57	12539.25
5	16778.98	8856.66	13888.26
6	19938.26	10025.20	16328.58
7	22492.37	12937.37	18324.17
8	23380.08	13205.91	19122.49
9	23740.33	13341.12	19446.7
10	23921.58	13476.95	19609.85
total	162509.71	91540.35	139273.12

Table 4. Cumulative Production of Piogas for the Three Digesters

Day	V (cm^3) digester A	V (cm^3) digester B	V (cm^3) digester C
1	3829.1	2974.38	4731.75
2	9513.19	6803.48	11941.32
3	18369.85	12487.57	20013.82
4	32258.11	19697.14	32553.07
5	49037.09	28553.8	46441.33
6	68975.35	38579	62769.91
7	91467.72	51516.37	81094.08
8	114847.8	64722.28	100216.57
9	138588.1	78063.4	119663.27
10	162509.7	91540.35	139273.12

Tables (3, 4) and Figures (12, 13) show the Kinetics and cumulated production of biogas for the three digesters. For the same retention time the biogas production is about 1.2 to 1.8 times, the green sample is greater than others.

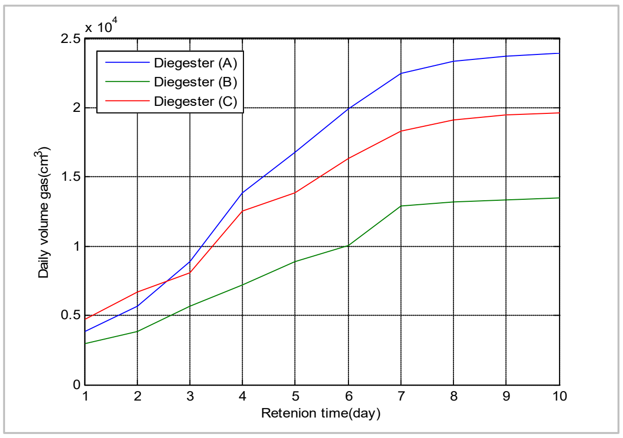

Fig.12. Kinetics production of biogas for the three digesters

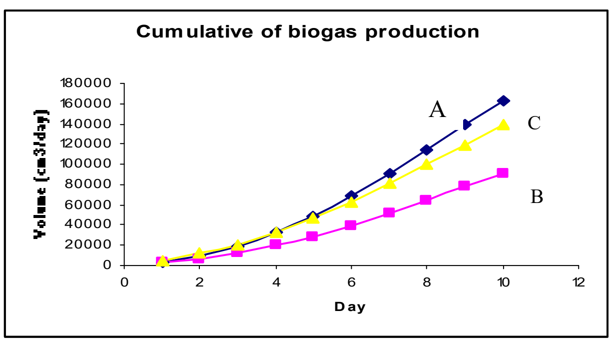

Fig. 13. Cumulative production of biogas for the three digesters

8. CONCLUSIONS

This study sheds light on the effect of Water Hyacinth on the environment and its benefits in the production of biogas by the anaerobic fermentation in batch digester. The objective of the research is to study the optimum conditions for the production of biogas. The production of biogas, temperature and pH were recorded for three sample green, dry and mixed green and dry, the three laboratory scales anaerobic digesters systems had been proven the possibility production of biogas from Water Hyacinth.

For further studies treatment unit can be added to enhance the system and produce methane gas.

ACKNOWLEDGEMENTS

The authors would like to thank the Minstery of High Eduction and Scinitific Research in Sudan , for the financial support provided to the project .

REFERENCES

[1] Almoustapha , S. Kenfack, MillogoRasolodimby(2008) Biogas production using water hyacinths to meet collective energy needs in a sahelian country . Field Action Science Reports , Vol.1

[2] John Momanyi Mironga (2011). The effect of water Hyacinth, Eichhornia Crassipes, infestation on phytoplankton productivity in Lake Naivasha and the status of control. Department of Geography, Faculty of Environment and Resource Development. Egerton University. PO Box 536. Njoro. Kenya .

[3] Ruihong Zhang., (2012). Biogas Production Technologies. Biological and Agricultural Engineering, University of California, Davis, June.

[4] . H. Culhane., (2017). Biogas Digester. Tamera, Solar Village Valerio Marazzi – ARCò.

[5] Teodorita Al Seadi, Dominik Rutz, Heinz Prassl, Michael Köttner, Tobias Finsterwalder,. Silke Volk, Rainer Janssen, (2008). Biogas handbook. Published by University of Southern Denmark Esbjerg, Niels Bohrs Vej 9-10, and DK-6700 Esbjerg, Denmark.

[6] Arielle Tonus Ellis., (2011). Invasive Species Profile Water Hyacinth, Eichhoria crassipes. South America

[7] Amrit B. Karki. , Amrit Man Nakarmi. , Ram Prasad Dhidal,Isha Sharma , Pankaj Kumar , (1996). Biogas technology: a training manual for extension. Food and agriculture organization of the United Nations . Nepal.

[8] Laurel Erika Rowse., (2011). Design of Small Scale Anaerobic Digesters for Application in Rural Developing Countries. University of South Florida.

[9] Krzysztof. Z and Magdalena. F., (2012). Methane fermentation process as anaerobic digestion of biomass: Transformations, stages and microorganisms. African Journal of Biotechnology Vol. 11(18), pp. 4127-4139.