

Production of biogas using waste products (Water Hyacinth and Cow Dung)

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Abstract

This research was carried out to make use of water hyacinth to produce biogas which may solve the problem of water hyacinth management as well as provide a solution to energy and power shortages. Samples of water-hyacinth were identified and collected and the cow dung was obtained from an abattoir. One (1) single 120 improvised rubber cylinder can be used as an anaerobic. Three (3) of water was added for the 30 days retention time. The cow dung was mixed with water at a ratio of 3 : 1. The slurry of cow dung and water hyacinth substrates was then fed to the for the fermentation process to begin. Experiments were carried out during the cool season and dry season (20– 40* C). The gas was collected and stored in the gas bag. The volume of was measured using an EL- STER HANDEL GMBH MAINZ volumetric meter, which has a limit of detection of less than 0.0010m³. The products obtained from the anaerobic digestion of water hyacinth were the compost that is removed from the at the end of the digestion process. The study's evaluation of production potential over a 30 days period revealed marked seasonal variations in biogas outflow.

1 Introduction

1.1 Background of the Study

Nigeria is a country blessed with abundant energy resources. These are the primary energy sources such as crude oil, natural gas, coal, and renewable energy most of which are underutilized such as hydro, wind, solar, biomass, and fuel wood. Most of the energy needs of Nigerians for household and industrial use are petroleum-based namely petrol, diesel, kerosene, and natural gas. While kerosene and gas are used extensively by most households in urban areas, the rural dwellers, which form 70-80% of the population, depend almost exclusively on fuel wood for household use. This high dependence on fuel wood for domestic and commercial purposes is a matter of public concern as it is the major cause of deforestation in many parts of the country and with implications cause of global warming. Since the rate of regeneration of wood is not commensurate with the high rate of consumption, there is an increasingly high rate of desert encroachment, soil erosion, and loss of soil fertility in places with high rates of deforestation. Thus complete reliance on fuel wood to meet the domestic energy needs of rural communities enhances environmental degradation - a situation that is very difficult to reverse. One of the ways of saving the environment from further deterioration and also supplementing the energy needs is by the production and use of biogas by the rural communities. The technology of biogas production is not new. The development and construction of biogas digester started in the I920s and has spread to several developing countries such as India, Taiwan, etc. In these countries, biogas technology has supplemented a large proportion of the energy requirements of the

rural majority. The availability of raw materials coupled with the ever-increasing prices of fossil fuel has made this technology attractive.

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 concerns for depleting oil reserves, rising crude oil prices, and the greenhouse effect. A lignocellulosic feedstock is considered an attractive raw material because of its availability in large quantities at low cost (Mosier *et al.*, 2005) not only for the liquid transportation fuel but also for the production of chemicals and materials, i.e. the development of carbohydrate-based biorefineries (Machunga-Disu *et al.*, 2012). Besides terrestrial plants, aquatic plants are also promising renewable energy resources. Water hyacinth, *Eichhornia crassipes* is such an aquatic plant.

Biomass is an important renewable resource that may replace petroleum-based energy and chemicals (Han, 2013 and Yoon, 2014). However, global warming and depleting crude oils have compelled us to switch towards renewable energy. Some plants like water hyacinth (*Eichhornia crassipes*) quickly grow to very high densities (over 60 kg/m²), thereby completely clogging water bodies (Julien, 1996). The mixture of animal waste and water hyacinth resulted in better biogas yields (Kumar, 2005) and the sludge obtained from mixed feed had better nitrogen, phosphorus and potassium content which could serve as very good manure. Water hyacinth proved to be a promising substrate for anaerobic digestion with its digestion resulting in high biogas yields (267 L/kg VS) (O’Sullivan, 2010).

Water-hyacinth is an invasive alien species in waterways. According to MWBP/RSCP (2006), the International Union Conservation of Nature (IUCN) identified the plant as one of the 100 most aggressive invasive species. While the study conducted by Gichuki *et al.*, (2012) recognized the plant as one of the top ten (10) worst weeds in the world. The plant is also listed by law in Africa as a pernicious weed with the widest spread damaging aquatic plant species. UNEP (2012), reported that the plant is difficult to manage and control, thereby threatening economic development (Alimi and Akinyemiju, 1991), human well-being (Toft *et al.*, 2003; Hellman *et al.*, 2008 and Varshney *et al.*, 2008) and biodiversity (Villamagna and Murphy, 2010); thereby flourishing continuously in all surfaces of freshwater, wetlands, and estuaries, appearing in cluster population and forming a heavy dense mat. In Nigeria almost all river bodies have been dominated by water hyacinth. Cossil *et al.*, (2001) documented that the plant proliferation resulted in the reduction of maritime business, irrigation, house boat rental services, access to water for riverine settlement and recreational activities; thereby, increasing evapo-transpirational as well as fish losses (Irving and Beshir, 1982). Studies have revealed that human activities (Dagno *et al.*, 2012) have led to the spread of the plant as well as the lack of naturally occurring enemies that are capable of suppressing their spread. Shoeb and Singh (2002), ascertained that when conditions are favourable the plant can flourish well and can reach a mass density of 17.5 metric tonnes per hectare per day, and by conversion this value is equivalent to 6387.5 metric tonnes per hectare per annum thus its need in biogas production. Studies have also revealed that to keep the plant at an unproblematic level, the control methods that are often used includes physical – mechanical (Patel, 2012), biological (Simberlof and Sliling, 2003; Dagno *et al.*, 2012 and Venter *et al.*, 2012) and chemical (UNEP, 2013) methods. Therefore, the plant has found application in fire board production, organic fertilizer production, rope making, paper production, animal fodder, mat and basket making, water purification, fish feed formulation, charcoal briquetting, remediation of crude oil contaminated soil and bio fuel production such as biogas, bio-ethanol and biodiesel (Jayaweera *et al.*, 2007; Almoustapha *et al.*, 2009; and Kunatsa and Mufundirwa, 2013). According to Wang and Calderon (2012), water hyacinth can be a potential resource to produce biogas and bioethanol as supported by other researchers (Akinwande *et al.*, 2013; Gunnarsson and Petersen 2007; Cheng *et al.*, 2010 and Kunatsa and Mufundirwa, 2013). According to Zulu and Richardson, (2013), it can therefore, be a good alternative for the production of energy as more than 80% of urban households in sub-Saharan Africa use charcoal as their main source of cooking energy.

1.2 Statement of the Problem

One of the most pressing problems of our industrialized society is the uncertainty of maintaining an adequate supply of energy. Fossil fuels continue to decline in availability, because it is not renewable so the search for alternative sources of energy has to be intensified. One alternative source of energy is the production of methane gas (Biogas) by the anaerobic digestion of various types of biomass.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this work is the use of water hyacinth to produce biogas which may solve the problem of water hyacinth management as well as provide solution to the energy and power shortages.

1.3.2 Objectives

1. To produce biogas using water hyacinth
2. To produce an environmentally friendly agricultural fertilizer and soil conditioner
3. To reduce water pollution caused by water hyacinth
4. To encourage the use of biogas in cooking instead of firewood
5. To create public awareness in all aspects of the weed

1.4 Significance of Study

The dependence on fossil fuels as primary energy source has led to global climate change, environmental degradation, and human health problems. Moreover, the recent rise in oil and natural gas prices may drive the current economy towards alternative energy sources such as biogas. Security of energy supply especially sustainable energy and reduction of CO₂ emission are priorities and biogas fuel helps to reduce greenhouse gas emissions. Domestic biogas installations can reduce greenhouse gas (GHG) emissions in three ways: by changing the manure management modality; by substituting fossil fuels and non-renewable biomass for cooking (and to a smaller extent for lighting) with biogas, and; by substituting chemical fertilizer with bio slurry. Utilizing biogas as an alternative to fossil based fuels reduces the net amount of carbon dioxide emitted to the atmosphere. Biogas is regarded as carbon neutral fuel because CO₂ released is utilized by plants for photosynthesis which creates organic matter from it. The use of renewable energy sources can contribute to solve the present and future energy problems. Among the alternative energy sources, biogas production from green energy crops and organic wastes has world wide application as it yields a good quality fuel and fermented slurry, which may be used as a manure or soil conditioner.

2 Literature Review

2.1 The Biology of Water Hyacinth

The family Pontederiaceae has nine genera including Eichhornia, which has eight species of freshwater aquatics including water hyacinth (*Eichhornia crassipes*) (Barrett, 1988). Only *E. crassipes* is regarded as a pan-tropical aquatic weed (OEPP/EPPO, 2008). The name water hyacinth refers to its aquatic habitat and the similarity of the flower color to that of the garden hyacinth (Parsons & Cuthbertson, 2001). Water hyacinth (WH), a free-floating macrophyte, live at the air-water interface and form two distinct canopies: leaf canopies comprising above-water structures and root canopies comprising below water structures. The English common names of the plant are waterhyacinth, water hyacinth, and water-hyacinth. Waterhyacinth is the standardized spelling adopted by the Weed Science Society of America to denote that it is not an aquatic relative of true “hyacinth” (*Hyacinthus* spp.) (Center *et al.*, 2002). Synonyms are *Eichhornia crassipes* (Mart.

and Zucc.) Solms, *Pontederia crassipes* (Mart. and Zucc.), *Piaropus crassipes* (Mart. and Zucc.) Britton (Penfound & Earle, 1948). Water hyacinth is an erect, free-floating, stoloniferous, perennial herb (Center *et al.*, 2002). The mature WH consist of roots, rhizomes, stolons, leaves, inflorescences and fruit clusters (Penfound & Earle, 1948) **See figure 2.1.**

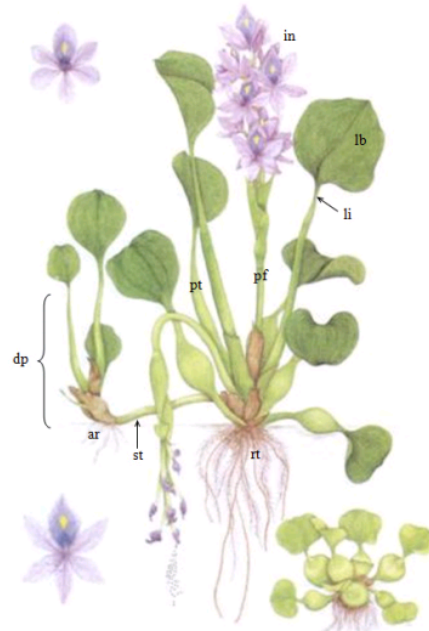


Figure 2.1 (Morphology of water hyacinth with stolons) (source: Parsons and Cuthbertson, 2001)

ar: adventitious root

dp: daughter plant

in: inflorescence

lb: leaf blade

li: leave isthmus

pf: peduncle of the flower spike

pt: petiole

rt: root

st: stolon

2.1.1 Petioles:

Water hyacinth petioles are either erect (up to 60 cm long and bearing flowers) or horizontal (stolons), about 10 cm long, and produce new plants from terminal buds (Parsons & Cuthbertson, 2001).

2.1.2 Leaves:

There are two types of leaves. Some are up to 60 cm long, narrow, and stand erect; others are almost round, up to 30 cm in diameter, and curved upwards with edges somewhat undulate. Both are smooth, glabrous, glossy, and with semi-parallel veins following the curvature of the leaf. Leaf stalks can be 50 cm long with bladder-like swellings, either bulbous or elongated, consisting of large air cells enabling the plant to float on water (Parsons & Cuthbertson, 2001).

2.1.3 Flowers:

Water hyacinth flowers are attractive mauve with six lobes or petals. The uppermost petal has a yellow dot in the center surrounded by darker purple. Each spike consists of about 8 (ranging from 3 to 35) flowers and individual flowers last only a few days. New plants flower when only 3 or 4 weeks old (Parsons & Cuthbertson, 2001). Under favorable conditions, WH may flower repeatedly throughout the year; although the intensity of flowering may vary with seasonal variation in growth rate.

2.1.4 Fruits and seeds:

The fruit consists of a narrow 3-celled capsule about 1 to 1.5 cm long, containing up to 300 seeds. Seeds are about 1 to 1.5 mm long with many longitudinal ribs. The seeds can germinate in a few days. In cool temperature areas, they remain dormant for 15 to 20 years in dry mud, germinating when moistened. A temperature of 20 to 35°C usually enhances germination. In other words, rapid growth occurs with increasing summer temperature (Parsons & Cuthbertson, 2001).

2.1.5 Roots:

The root morphology is highly plastic, fibrous and has one single main root with many laterals, forming colossal root system. Because each lateral root has a root tip, WH may exploit nutrient in a low-nutrient water body (Xie & Yu, 2003). Lateral roots are generally longer and denser at low phosphorus levels than at high phosphorus levels (Xie & Yu, 2003). In shallow water, the roots may become attached to the bottom for several weeks when the water level drops (Parsons & Cuthbertson, 2001). The root-shoot ratio varies inversely with nutrient level, particularly with respect to nitrogen. Purple roots are characteristic of plants when nutrient levels are low in the water. (Xie & Yu, 2003)

2.2 Chemistry of Water Hyacinth: (Jafari 2010)

- The fresh plant contains 95.5% moisture, 0.04% N, 1.0% ash, 0.06% P_2O_5 , 0.20% K_2O , and 3.5% organic matter.
- On a zero-moisture basis, it is 75.8% organic matter, 1.5% N, and 24.2% ash.
- The ash contains 28.7% K_2O , 1.8% Na_2O , 12.8% CaO , 21.0% Cl , and 7.0% P_2O_5 .
- It contains, per 100 g, 0.72 g methionine, 4.72 g phenylalanine, 4.32g threonine, 5.34 g lysine, 4.32 g isoleucine, 0.27 g valine, and 7.2 g leucine.
- Water hyacinth roots naturally absorb pollutants, including such toxic chemicals as lead, mercury, and strontium 90 (as well as some organic compounds believed to be carcinogenic) in concentrations 10,000 times that in the surrounding water.

2.3 Value-Added Products from Water Hyacinth

2.3.1 Biofertilizer :

Water hyacinths can be used on the land either as manure or as compost. As a manure, it may be plowed into the bottom or used as mulch. The plant is good for composting; microbic decomposition breaks down fats, lipids, proteins, sugars, and starches. The mixture may be left in piles to compost; the warmer climate of tropical countries accelerates the method of manufacturing, rich pathogen-free, compost which

may be applied to the soil. The study conducted by (Vidya and Girish, 2014) discovered that WH is used as a biofertilizer once incorporated into soil inflated the performance of the wheat plants. In this study, the wheat crop was treated with compost derived from WH and was big for fifteen days. Management experiments were carried out while not WH compost. Physical and chemical parameters were studied. The physical parameters like proportion germination, length of root, length of shoot, biomass content, and root: shoot ratios were studied. Chemical parameters like pigment, reducing sugar, and supermolecule content was conjointly evaluated. The study revealed that each physical and chemical parameter had higher values as compared to regulate. WH may be a sensible absorbent material of N, P, and K from the water and may be used as a compost material. The results indicate the potential of WH as organic manure.

2.3.2 Bioethanol:

Depletion of fossil fuels and increase in energy consumption leads to hunting for various methods of energy. The utilization of lignocellulosic feedstock will be thought about as an appropriate biomass for the production of renewable biofuels like bioethanol. Production of fuels from waste biomass like WH plays a very important contribution to independent society. Bioethanol production from WH involves 3 stages-pretreatment, chemical reaction, and fermentation. Bioethanol could be a renewable fuel and its importance will increase due to the depletion of fossil fuels, an increase in oil worth, and inexperienced house impact. Bioethanol production from recent and dry WH exploitation ruminant microorganisms and ethyl alcohol producers was evaluated by Sambo *et al.*, (2015). The study discovered the potential of microorganism and flora isolates obtained from the first stomach of goat, ram, and cow to digest cellulosic materials of WH. Fermentation of the WH product was distributed with *Saccharomyces cerevisiae* and *Zymomonas mobilis*. The results indicate that *Zymomonas mobilis* made more bioethanol than *Saccharomyces cerevisiae* moreover and the recent WH biomass made additional bioethanol than the dried WH biomass. The employment of WH for the assembly of bioethanol will go an extended means in reducing dependence on fuel.

2.3.3 Biohydrogen: Due to the depletion of fossil fuels and the increase in energy demand scientists everywhere around the globe square measure sorting out various ways of energy. Biohydrogen is energy since its combustion generates solely water and warmth in addition as has a high energy yield of 122 kJ/g. historically gas is created by a chemical process involving electrolysis of water and steam reforming. These processes don't seem to be economically viable since it needs high energy input and high reaction temperature. Biohydrogen production is eco-friendly and might be created from a mixed or pure culture. Many anaerobic microorganisms will turn out biohydrogen from organic wastes (Sindhu *et al.*, 2017). Muanruksa *et al.*, 2016; Reported direct biohydrogen production from WH victimization clostridia diolis C32-KKU. polyose and hemicelluloses given in WH are directly hard by the cellulolytic bacterium clostridia diolis C32-KKU to biohydrogen. Various process parameters touching biohydrogen production were optimized for each static and shaking mode of cultivation. The study discovered that shaking mode was simpler than static mode for biohydrogen production. Most biohydrogen production (19 ml/l) was discovered at a pH scale of 5.5 and WH biomass loading of 19gdw/l. The results of the study indicate that direct biohydrogen production from WH might be a possible approach.

2.3.4 Animal Feed: Water hyacinth is a good source of animal feed due to its protein and mineral content. Studies have proved that the nutrients in water hyacinths are available to ruminants. Water content in water hyacinth must be reduced from 95% to about 15% or less than that to prevent spoilage (Chakraborty *et al.*, 1991). The use of water hyacinths for animal feed is encouraged in developing countries to help solve some of the nutritional problems (Jafari, 2010).

2.3.5 Fish Feed:

The Chinese grass carp may be a quick-growing fish that grub aquatic plants. It grows at an incredible rate and reaches sizes of up to 32 kilograms. It associates edible fish with tasty pork. It'll eat submerged or floating plants and conjointly bank grasses. The fish is used for weed control and can eat up to 18–40% of its own weight in a very single day (Gopal, 1987). *Eichhornia crassipes* have conjointly been used indirectly

to feed fish. Dehydrated water hyacinth has been value-added to the diet of catfish fingerlings to extend their growth (Gopal 1987). It's conjointly been noted that the decay of *Eichhornia crassipes* once chemical management releases nutrients that promote the expansion of flora with a resultant will increase in fish yield (Gopal 1987). Igbinosun and Talabi (1982) conducted a study that proved that water hyacinth feed has more fiber, and fat content and was found suitable in comparison to NIOMR (Nigerian Institute for Oceanography and Marine Research) fish feed. The addition of dehydrated water hyacinth to the diet of channel catfish fingerlings led to an increase in their growth. (Gopal, 1987).

2.3.6 Water Purification:

Water hyacinths are often wont to aid the method of water purification either for drinking or for liquid effluent from waste matter systems. In a drink treatment plant, the water plant has been used as a part of the pre-treatment purification step. Clean, healthy plants are incorporated into water clarifiers and facilitate the removal of little flocs that stay when initial coagulation and material removal or subsiding. The result's a big decrease in turbidity thanks to the removal of flocs and additionally a slight reduction in organic matter in the water. In waste matter systems, the basic structures of water plants (and alternative Aquatic plants) offer an appropriate atmosphere for the aerobic bacterium to operate (Mathur & Mathur 2018). Water Hyacinth (*Eichhornia crassipes*) was used to treat domestic wastewater. Ten organic and inorganic parameters were monitored for three weeks for water purification. The six chemical, biological and physical parameters included Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH₃-N), Total Suspended Solids (TSS), and pH were compared with the Interim National Water Quality Standards, Malaysia River classification (INWQS) and Water Quality Index (WQI).and observed Reduction in the most of the parameters like DO, COD, BOD, (NH₃-N) and TSS by *Eichhornia crassipes* occurred which is due to the successful phytoremediation treatment system. In this case, the increase of CO₂ levels from photosynthesis and microbial activities have played a key role. Based on the results, the water quality has been improved from class IV and III to class II which is due to a 38% to 96% of reduction of parameters. In this study, the highest reduction was in the range of 13- 17th day of the experiment but the optimum was recorded on day 14 in a continuous system.

2.3.7 Biogas:

Biogas is an ideal clean energy source, and the development of biogas can improve ecological and environmental conditions, such as by reducing the deforestation of forests. Biogas can be used for cooking and generating electricity. Biogas residue contains regular nutrients, organic matter, trace elements, amino acids, and vitamins, etc., which makes both quick and slow organic compound fertilizers. The water hyacinth C/N ratio is approximately 20:1. Under anaerobic conditions, microorganisms can use their nutrients for the anaerobic fermentation of methane (Chen, 2007). Gunnarsson *et al.*, found that water hyacinths and other aquatic plants are able to be easily degraded. The anaerobic fermentation produces large amounts of gas, which not only solves the problem of water hyacinth breeding but can also generate energy, turning waste into a valuable resource. (Gunnarsson, 1886).

2.3.8 Medicinal Uses:

Water hyacinth has long been used to treat goiter in India. The formulation contains water hyacinth in equal quantities with table salt and piper congom. A study by Feikin *et al.*, 2010 investigated the vitamin c contents of tropical plants and weeds including water hyacinth by cyclic voltammetry (CV) and titration with N-bromosuccinimide (NBS) and their relevance to medicinal uses of plants. Results related the role of ascorbic acid determined as 10.19 mg/100 g by CV and 16.34 mg/100 g by NBS in water hyacinth to its relevant medicinal uses like skin care and goiter.

2.3.9 Carbon Source:

Protein hydrolysate of water hyacinth, singly or in combination with hydrolysate of pea husk has been used in yeast extract mannitol medium for the cultivation of rhizobium sp. (Tucker and Debusk, 1981). Water hyacinth cellulose was exploited as the sole carbon source in the culture medium for the production of cellulose base-rich preparation by *Aspergillus niger*.

2.3.10 Others: Water hyacinth can be used as a raw material for the production of pulp, paper, rope, basket and various other products which can be used for the development of small scale industries. Water hyacinth is used in the production of fiber boards and bituminized boards for use as a low-cost roofing material (Jafari, 2010). The stalks of water hyacinth have the potential to be pulped and converted into medium-quality papers or boards such as cardboard and colored cards or cover papers, the shrinkage of paper during drying can also be minimized by blending them with long fibrous pulps such as cotton rags and waste paper pulps). Goswami and Saikia, 1994 demonstrated the role of aquatic weed as a raw material for pulp and paper, and fiber for making chairs, mats, and baskets. Goswami and Saikia (1994) investigated the use of water hyacinth as a pulp material for producing greaseproof paper.

2.4 Water Hyacinth Reproduction

Water hyacinth does both sexual and asexual reproduction and the modes are equally important to the species' success as a destructive aquatic intruder. In calm climates, the weeds can flower throughout the year, and from early spring to late fall in other places. Growth rates are explosive and vegetative population doubling can take place in 1-3 weeks (Wolverton and McDonald 1978). They are capable of yielding an abundance of seeds making water hyacinths have a growth rate of 17.5 metric tonnes per hectare per day. An investigation by Barrett (1988) confirmed that tropical *E.crassipes* populations produced twice as many seeds as moderate populations and ascribed the difference to higher rates of pollinating insect visitation in the tropics. Seed germination has a propensity to take place when water levels are low and the seedlings can grow in drenched soils. Vegetative reproduction occurs via the breaking off of rosettes of clonal individuals. The stolons (horizontal shoots capable of forming new shoots and adventitious roots from nodes) are easily broken down by wave or wind action and floating clonal plants and mats are readily transported by water or wind movement (Barrett 1988).

2.5 Ecological Characteristics of Water Hyacinth

Water hyacinth reproduces vegetatively through the formation of stolons, and is also sexually propagated through seeds, which can survive in water for six years making water hyacinth difficult to control. Under suitable growth conditions, the number of water hyacinths can double in one week (Tag El-Din, 1992). A water hyacinth plant can produce 140 million ramets within one year, with a fresh weight of 28,000 tons (Ogutu-Ohwayo, 1997). Water hyacinths are prevalent in eutrophic water bodies and can form dense grass mats covering large areas of water. Akinwande *et al.*, studied the water hyacinth biomass in Nigerian waters, which ranged from 28.8 to 33.2 t dry matter/(ha·year) (Akinwande, 2013). The water hyacinth has a well-developed root system and can absorb nutrients in the growing environment. Therefore, its material composition is closely related to the growth environment. Poddar *et al.*, reported that water hyacinths growing in swamp areas with a nitrogen content of 2.40 mg/L had a nitrogen content of approximately 1.78%. (Poddar, 1991).

2.6 Habitat

Water hyacinth rapidly colonizes still or slow-moving water, resulting in thick extensive mats. It occurs in estuarine habitats, lakes, urban areas, water courses, and wetlands (Gopal, 1987). It prefers nutrient-enriched waters and can tolerate considerable variation in nutrients, temperature, pH levels, and toxic substances (Gopal, 1987). Growth occurs in a wide range of temperature from 1 to 40°C but is most favorable under

warm conditions with a maximum growth at 25 to 27.5°C (Wilson *et al.*, 2005). Plants tolerate acidity levels as low as pH 3 (DiTomaso & Healy, 2003) but optimum pH for growth is 6 to 8 (Wilson *et al.*, 2005). However, WH does not tolerate salinity above 1.6‰ (DiTomaso & Healy, 2003) and there is no evidence to indicate that this fresh water plant can adjust to saline water (Penfound & Earle, 1948).

2.7 Control Methods for Water Hyacinth

Mechanical, chemical, and biological control methods are commonly used to control WH (Julien *et al.*, 2001), but no one method is suitable for all situations (Gopal, 1987).

2.7.1 Mechanical

Mechanical control includes harvesting by hand or machine (Villamagna & Murphy, 2010). The use of machinery to remove WH from water bodies is the most effective non-polluting control method (Mara, 1976), especially in critical areas such as hydroelectric dams and ports. The main advantage to the use of mechanical harvesting is the simultaneous removal of nutrients and pollutants from the water body, and may therefore act as a means of slowing or even reversing eutrophication (Wittenberg & Cock, 2001). Mechanical harvesting of WH has also resulted in rapid increases in dissolved oxygen, and improved suitability of the habitat to support fish. However, it requires recurring efforts involving machine and labor inputs (Mara, 1976). Mechanical removal with harvesters is also slow and therefore not suitable for large mats. Studies have shown that the costs of mechanical harvesting are on average US\$ 600 to 1,200 per hectare, about six times more expensive than chemical treatment using glyphosate (Wittenberg & Cock, 2001).

2.7.2 Chemical

Chemical herbicides are the principal means of control when an immediate solution to a WH problem is needed (Charudattan, 1986). Glyphosate and 2, 4- D [(2, 4-dichloro phenoxy) acetic acid] have been the most widely used herbicides and are considered effective and safe herbicides to control WH (Chen *et al.*, 1989; Charudattan, 1986). They are relatively cheap, with costs per hectare for aerial application of US\$ 25-200 (Wittenberg & Cock, 2001). Treated plants die and decompose in a few days to a few weeks. Despite such effectiveness of herbicides, the major disadvantages are that they are non-selective and could cause major environmental problems if incorrectly applied (Wittenberg & Cock, 2001). Chemical control needs to be carried out repeatedly as re-infestation of WH occurs from seeds or clonal multiplication of surviving plants (Chen *et al.*, 1989; Charudattan, 1986).

2.7.3 Biological

When chemical control is economically unfeasible or harmful to the environment, biological control is recognized as a cost effective, permanent and environmentally friendly control method. Using natural enemies from their original ecosystem is a prime target for biological control. Since 1971, two South American weevils, *Neochetina eichhorniae* and *Neochetina bruchi*, have been widely introduced in Australia, Asia and Africa (Wittenberg & Cock, 2001). In some areas, they have provided considerable control, but this is not consistent in all areas. The principal drawback with biological control of WH is the time required to achieve control. In tropical environments, this is usually 2 to 4 years and is influenced by the extent of the infestation, climate, water nutrient status, and other control options (Wittenberg & Cock, 2001).

2.8 Biogas

Biogas is a mixture of colorless, flammable gases produced by the anaerobic fermentation of organic waste materials. Biogas is a mixture of methane, carbon dioxide, small amounts of carbon monoxide, hydrogen, nitrogen, oxygen, hydrogen-sulphide, and hydrocarbon gas. The actual percentage of each gas varies with raw materials, the ratio of input materials, temperature, and fermentation stages. Typically the composition of biogas is as follows (Fernando and Dangaggo 1986).

Methane-54 -70%

Carbon monoxide-0.1%

Carbon dioxide-27-45%

Oxygen-0.1%

Nitrogen-0.5-3%

Hydrogen sulphide- Trace

Hydrogen-1-10%

Methane is the major combustible component of biogas. Others usually in small quantities are carbon dioxide, hydrogen, and hydrogen sulphide.

Biogases are obtained by the fermentation of organic materials such as animal, human, agricultural and industrial wastes. These include animal feces, municipal sludge and garbage, abattoir waste, paper waste, and waterweeds. The rate of conversion of the organic waste to the end products at an appropriate temperature depends on the complexity of the waste. In the treatment of complex wastes such as sewage and slaughterhouse waste, generally slower loading rates should be used due to the much slower conversion rate of the biodegradable suspended compounds than of the soluble compounds such as young plant materials. It is thus expected that the complexity of the waste is a significant factor that affects the rate of anaerobic digestion of any type of waste.

2.8.1 Biogas Production

A study carried out by Almoustapha *et al.*, 2009, revealed that it is possible to produce biogas from a mixture of water hyacinth and fresh rumen residue. Chanakya *et al.*, 1993; Kivaisi and Mitla, 1998; Kumar, 2005 as well as Kunatsa *et al.*, 2013 among other authors confirmed the possibility of producing biogas from water hyacinth. Almoustapha *et al.*, 2009, highlighted that biogas outflow is related to seasonal variations in temperature. For the same retention time, the total volume of biogas obtained during the warm season is 1.8 times greater than that obtained during the cool season. According to Nijaguna (2002), aquatic plants generate high-quality biogas but their salinity of 35-50 parts per 1000 is a serious problem. Water hyacinth generates biogas that has greater methane content and more soil nutrients than digested dung. Nijaguna highlights that water hyacinth produces 20.3 liters of biogas per kg of dry matter. On the other hand, Dr. Jagadeesh, 1990, noted that a hectare of water hyacinth can produce enough biogas each day to generate between 90 and 180 cubic meters of methane, equivalent to 3.44 to 6.88GJ of energy production. Despite the serious drawbacks, water hyacinth invasions in lakes can be harnessed for environmental benefit and renewable energy production. Water hyacinth has a very high cellulose content making them a potential renewable energy source. While controlling water hyacinth populations has proven to be beyond the capabilities of local government, using these plants for energy production provides an alternative approach to dealing with this invasive species. Water hyacinth can be used to produce biogas, an energy source that already has been embraced the world over. An investigation into the possibility of bio-converting water hyacinth to yield biogas adds value and solves the problem of water hyacinth management as well as gives a solution to the energy and power shortages since people would no longer rely on the expensive LPG or grid electricity. Biogas will lead to reduced use of fuel wood and diesel generators hence an innovative technology to the reduction of greenhouse gas emissions. Besides energy production, other valuable products, such as high-quality bio-fertilizer are obtained from the anaerobic digestion of water hyacinth and this will minimize the use of expensive mineral fertilizers. The option of biogas production as a way of energy exploration using water hyacinth may not only sustain the energy availability but also improve environmental sustainability by improving the social, economic, and physical well-being of the environment.

2.8.2 Process

The anaerobic digestion process involves a high number of microorganisms, which convert the feedstock to methane and carbon dioxide-rich biogas through a series of biochemical reactions that can be described by four steps, viz. hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These microorganisms include hydrolytic bacteria, acid-forming bacteria (acidogens), acetic acid-forming bacteria (acetogens), and methanogenic bacteria (methanogens).

- **Hydrolysis** In the first step, hydrolysis, the complex molecules of carbohydrates, proteins, and lipids are split into simple components (sugars, fatty acids, and amino acids) with the help of extra-cellular enzymes secreted by microorganisms which are mostly obligate anaerobes. A complex consortium of microorganisms participates in the hydrolysis and fermentation of organic material. It is the first step is inhibited by lignocellulose-containing materials, which are degraded only very slowly or incompletely (Rilling, 2005).
- **Acidogenesis** It is the second phase; the monomers produced in the hydrolysis phase are further degraded by fermentative bacteria into short-chain organic acids, with one to five carbons (valeric acid, butyric acid, propionic acid, acetic acid, and formic acid), alcohols, hydrogen, ammonia, and carbon dioxide. In a stable process, with a low partial pressure of hydrogen, the main products formed by the fermentative bacteria are acetate, carbon dioxide, and hydrogen. Acidogenesis products are volatile fatty acids (VFA), alcohols, aldehydes, hydrogen, and carbon dioxide. Decomposers are fermentative bacteria or anaerobic oxidizers. When the partial pressure of hydrogen is high, more intermediates such as volatile fatty acids and alcohols are formed.
- **Acetogenesis** In the third step, acetogenesis, the products of the acidification are converted into acetic acids, hydrogen, and carbon dioxide by acetogenic bacteria. Acetogenic bacteria such as *Syntrobacter wolini* and *Syntrophomonas wolfei* convert volatile fatty acids (e.g. propionic acid and butyric acid) and alcohol into acetate, hydrogen, and carbon dioxide, which are used in methanogenesis. The acetogenesis is regarded as thermodynamically unfavorable unless the hydrogen partial pressure is kept below 10⁻³ atm, by an efficient hydrogen removal pathway of hydrogen-consuming organisms such as hydrogenotrophic methanogens and/or homoacetogens. The first three steps of anaerobic digestion are often grouped together as acid fermentation. In acid fermentation, no organic material is removed from the liquid phase: it is transformed into a form suitable as a substrate for the subsequent process of methanogenesis.
- **Methanogenesis** The last step in anaerobic digestion is methanogenesis. The methanogenic microorganisms work under strictly anaerobic conditions. The methanogens, which belong to the group archaea, differ from the other organisms in the anaerobic reactor, which are bacteria. Archaea are more sensitive than bacteria with regards to environmental stresses in the reactor, such as pH, or toxic compounds such as heavy metals or different toxic organic materials. The methanogens mainly use acetate, carbon dioxide, and hydrogen, but also methylamines, alcohols, and formate for the production of methane. About 70% of the methane production arises from the acetate, and about 30% of the methane arises from hydrogen and carbon dioxide. The methanogens have the longest generation times (2-25 days) of the microorganisms in the reactor, which makes this step the most time-limiting step for easily hydrolyzed materials.

2.9 Factors Affecting Biogas Production

In order to enhance the performance of the biogas generation process, and to prevent process failure, certain operating parameters such as temperature, pH, nutrient addition, mixing ratio, and retention period, all need to be controlled. Microorganisms are highly sensitive to pH changes. Buffering is necessary for pH control and therefore an essential step in the overall operation (Garba and Sambo, 1992).

2.9.1 Temperature

Temperature is an important physicochemical factor in the degradation of organic wastes and as such the anaerobic process is dependent on temperature. The temperature has significant effect on biogas production especially when fresh plant material is involved. Two temperature ranges have been reported to affect the overall process of biogas production. These are; the mesophilic temperatures and thermophilic temperatures. The mesophilic temperature range of 30-40°C has been reported to effectively aid in degradation of organic wastes that are not lignified. Increased biogas production was reported in the digestion of fresh water weed known as *Pistia stratiotes* (water lettuce) at mesophilic temperature of 30 °C. The mesophilic temperature range is preferred when fresh plant material is involved (Maishanu, 1992). Also it is easier to maintain the digester at this temperature. Methane-producing bacteria are, very sensitive to sudden thermal changes and therefore any drastic change in temperature should be carefully avoided so that no abrupt decrease in gas production occurs. The digestion process must thus be designed to operate at constant temperature conditions. Temperatures above 65°C cause gas production to stop (Garba and Sambo, 1992).

2.9.2 pH

The anaerobic digestion process can be operated over a pH range of 6.0 — 7.0. As organic acids are produced during the breakdown of cellulose when the pH drops below 7.0, there is a significant inhibition of methanogenic bacteria and the acid conditions of a pH of 4.0 are toxic to these bacteria. At a pH of 4.0, the production of gas will be very low and later stops (Garba and Sambo, 1992). Several steps such as the introduction of bacteria having cellulolytic capacity, preheating the media material, milling the media material, chemical treatments with NaOH, etc, and drying have been shown to improve biogas yield (Itodo *et al.*, 1998). In the absence of water hyacinth, cow manure can be as an alternative raw material so that the plant will be kept running even after the water hyacinth has been eradicated.

2.9.3 Carbon to nitrogen (C/N) 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 the anaerobic digestion (FAO, 1996). 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 leftover carbon content of the material. 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. Solid concentration in the feed material is also crucial to ensure sufficient gas production as well as easy mixing and handling. The concentration of total solids in the input suspension can be varied within the range of 20 to 100g/liter. In practice, it is recommended to limit the total solids concentration to the range of 20 to 30 g/liter. In Nepal, 6 kg of cow dung per m³ of digester liquid volume is used (FAO, 1996). Cow dung has a solid concentration of about 20% and therefore, it is recommended that dung and water are mixed in a 1:1 ratio to attain the desired level of solids. One kilogram of dung produces about 40 liters of biogas. A family-size biogas plant (two cubic meters) requires 50 kg of dung and an equal amount of water to produce 2000 liters of gas per day. This amount of gas suffices the daily cooking requirement of a family consisting of four to five members.

2.9.4 Consistency and Dilution of Feedstock

All waste materials fed to a biogas plant consist of solid substances, volatile organic matter and non-volatile matter (fixed solids) and water. During the anaerobic fermentation process, volatile solids undergo digestion and non-volatile solids remain unaffected. According to a finding by The Energy and Resources Institute, fresh cattle waste consists of approximately 20% total solid (TS) and 80% water. TS, in turn, consists of 70% Volatile solids and 30% fixed solids. For optimum gas yield through anaerobic fermentation, normally, 8-10% TS in feed is required. This is achieved by making a slurry of fresh cattle dung in water in the ratio of 1:1. However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the input (i.e., the ratio could vary from 1:1.25 to even 1:2). If the dung is

too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of the gas formed at the lower part of the digester. In both cases, gas production will be less than optimum (Anonymous, 1981). It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of the digester will decrease.

2.9.5 Water Content

Bacteria take up the available substrates in dissolved form. Therefore, biogas production and the water content of the initial material are interdependent. Rilling (2005) reported that when the water content is below 20% by weight, hardly any biogas is produced. Optimum moisture content has to be maintained in the digester and the water content should be kept in the range of 60-95 %. Anaerobic digestion of organics will proceed best if the input material consists of roughly 8 % solids. For domestic digesters, TS content should not be too high, otherwise, the substrate would not slide easily through the inlet of the digester and if toxins are present, such as ammonium in high concentrations, high TS is likely to affect bacteria more than when the substrate is diluted. Alternatively, TS content should not be too low, otherwise, the feedstock is very dilute, and a large digester volume is required. Water content is one of the very important parameters affecting AD of solid wastes. There are two main reasons viz.; (a) water makes possible the movement and growth of bacteria by facilitating the dissolution and transport of nutrients and (b) water reduces the limitation of mass transfer of non-homogenous or particulate substrates.

2.9.6 Free Ammonia

A number of studies have cited the inhibitory effects of free ammonia (NH_3) on the metabolism of methanogens. As ammonia is added to a digester, the pH increases until a chemical equilibrium is reached. However, as ammonia inhibits methanogen metabolism, VFAs accumulate, resulting in a lower pH and a lower concentration of free ammonia. Sterling *et al.*, (2001) concluded that total biogas production was unaffected by small increases in ammonia nitrogen while higher increases reduce biogas production to 50% of the original rate. However, the underlying reason for this effect is still unknown. It was also found that the free ammonia concentration not only affects the acetate-utilizing bacteria, but also the hydrolysis and acidification processes. By controlling the pH value lower it is possible to control the production of ammonia but it lowers the yield of biogas production.

2.9.7 Seeding

To start up a new anaerobic process, it is critical to use inoculums of microorganisms to commence the fermentation process. The common seeding materials include digested sludge from a running biogas plant or material from sewage. Digested sludge is the best inoculum source for anaerobic thermophilic digestion of the treatment of an organic fraction of municipal solid waste at dry conditions (30% TS). Inoculums caused biogas production rate and efficiency to increase more than two times as compared to a substrate without inoculums. The addition of fresh cow dung to the batch reactor as part of the starter improves biogas production. When poultry litter was used as inoculum for an anaerobic process methane yield was best on a digester with a content of 75% of inoculum (Jagadish *et al.*, 2012).

2.9. 8 Particle Size

The production of biogas is also affected by the particle size of the substrate. Too big a particle size is problematic for microbes to digest and it can also result in blockage in the digester, whereas small particle size gives a large surface area for substrate adsorption and thus allows the increased microbial activity followed by an increase in the production of gas. A large amount of biogas was obtained from the grounded water hyacinth than chopped water hyacinth. Degradation of the substrate and biogas production potential of the water hyacinth could be significantly increased by pre-treatment such as a reduction of particle size.

These results suggest that the reduction of the particle size of the substrate in conjunction with the optimized microbial growth could improve the methane yields in anaerobic digestion processes (Yasini and Isack, 2016).

2.9.9 Agitation

The close contact between microorganisms and the substrate material is important for an efficient digestion process. The agitation of the digester contents has a number of benefits, one of the most obvious being that it helps to mix up material, evening out any localized concentrations, thus also helping to stop the formation of “dead zones” or scum. In addition, it increases the waste’s availability to the bacteria, helps remove and disperse metabolic products, and also acts to ensure a more uniform temperature within the digester. There have been some suggestions that efficient mixing enhances methane production, but the evidence is inconclusive, so it seems likely that this may only be of noticeable benefit for some systems or operational regimes. Mixing also promotes heat transfer, particle size reduction as digestion progresses, and release of produced gas from the digester contents. There is a significant stirring effect on the anaerobic digestion only when seed sludge from a biogas plant was used as a starter. In this case, the experiments without stirring yielded, without starter, only about 50% of the expected biogas for the investigated substrates.

2.9.10 Total Solids

Total solids mean the number of solid particles in the unit volume of the slurry and they are usually expressed in the percentage form (FAO/CMS, (1996). The percentage of total solid should be between 5% and 12% while other sources reported that the best biogas production occurs when total solid is ranged from 7% to 10% because of avoiding solids settling down or impeding the flow of gas formed at the lower part of the digester. Therefore; dilution of organic substrate or wastes with water to achieve the desirable total solids percentage is required. The total solid concentration of 99 g TS/l produces the maximum biogas yield as per the experiment done with different concentrations of total solid in an anaerobic digestion process (Sajeena, 2013).

2.9.11 Effects of Oxygen in AD

It is quite natural that some amount of oxygen can reach anaerobic digesters unintentionally as the reactors are operated within an aerobic open environment, especially through interactions with the surroundings such as by feeding and mixing. Most anaerobic digesters are therefore subjected to a minute and varying aerobic loading conditions. The possible effects of such aeration are neither extensively quantified nor handled in standard AD models. It is commonly perceived that oxygen acts as an inhibitory and toxic agent in AD due to the involvement of a strictly anaerobic microorganism group of acetogens and methanogens (D. Botheju *et al.*, 2010). Also, the aerobic conversion of soluble organic matter into CO₂ by aerobic respiration is likely. Thus, it was believed that reactor instabilities, slow start-ups, low methane yields, and even total reactor failures might occur due to oxygen entering anaerobic digesters. Due to this negative perception, inoculums used in anaerobic digesters are even de-aerated before commencing reactor operation; sometimes oxygen scavenging chemicals (e.g. sodium sulfide) are also added. Conversely, improved hydrolysis of particulate matter in AD is observed in the presence of oxygen. All non-soluble and long-chain organic matter should go through this initial hydrolysis stage before fermentation or methanogenesis, in which the particulate matter would undergo decomposition and solubilization by the activity of enzymes (such as protease, amylase, etc.) that are extracellularly excreted by fermentative (acidogenic) bacteria. Since hydrolysis is often the rate-limiting reaction stage when the substrate is composed of particulate organic matter enhanced hydrolysis can greatly benefit the overall process efficiency. It is commonly known that hydrolysis rates are significantly higher under aerobic and anoxic conditions compared to anaerobic conditions. Botheju *et al.*, (2010) demonstrated the possibility of the existence of an optimum oxygenation level that would yield a maximum methane generation in AD.

2.9.12 Retention Time

The retention time is the theoretical time that a particle or volume of liquid added to a digester would remain in the digester. It is calculated as the volume of the digester divided by the volume added per day, and it is expressed as days. The solid retention time represents the average time that the solids remain in the system. The solid retention time can be determined by dividing the weight of volatile solids in the system by the weight per unit time of volatile solids leaving the system. The hydraulic retention time (HRT) is equal to the solid retention time in completely mixed non-recycled digester systems. Retention time has an effect on gas production as shown in the results of (1974). There is a minimum retention time which allows the slowest growing bacteria to regenerate. Then there is a minimum. Retention time is required to achieve a satisfactory stabilization of the solids, which Dague shows as 10 days for sewage sludge at 35°C. If the retention time is cut in half, the gas production rate will drop and the process may fail due to a condition called wash out where the bacterial cultures decrease to the point that they are no longer effective. If the retention time is greater than 10 days at 35°C., the gas production levels out, and very little additional gas is produced for the additional time. Therefore, long detention times lead to low efficiency of the process. There is a tendency to refer to gas production rates in terms of volumes of gas produced per volume of digester volume. If maximum gas is desired, the ratio may be four or more volumes/volume per day. However, if the purpose of the digester is to produce and store a soil conditioner and to have some gas, as is the case in China, then the ratio may be very low and has no meaning. Retention time along with the temperature is important from the standpoint of the destruction of pathogens. If improved health is a consideration, certain minimum values should be exceeded.

2.9.13 Concentration of the Feed Stocks

Gas production is a function of the solid materials and their biodegradability in the digester. The more concentrated the solids, the smaller the digester and the lower the cost of the system. In sewage treatment plants, efforts are made to concentrate the solids to reduce the volume and the costs of the digester. The literature about the Indian digesters as reported by ESCAP (1980) implies that an optimal solids concentration of 7 to 9% of the feed should be used. However, systems have been designed to use as little water as possible. For example, Amon (2007) points out the advantage of dairy manure (10 to 13% solids) are that it can be added to the digester directly without dilution. If the manure has stood for a few days some water may have to be added to slurry the material for introduction into the digester. In Israel the manure is scrapped from the cattle pens with bedding which is either asphalt or concrete. Sterling (2001) reports that he has fed this manure with only small quantities of water at 16 to 18% solids content without difficulty. Batch dry digesters have operated with solids concentrations at 60%. The batch dry digesters with high solids concentrations appear to be an effective means of producing gas cheaply. Currently efforts are underway to manage and optimize the gas production for crop residues and urban solid wastes in landfills having very high solids.

2.9.14 Organic Loading Rate

The rate at which biomass is supplied to the digester is referred to as the volumetric organic loading rate and is commonly expressed in terms of grams of volatile solids per liter of digester capacity per day (gm VS/l-day). Different loading rates can be obtained by either changing the concentration of the solids in the influent or varying the flow through the digester. In practice the solids concentrations tend to be kept constant, and thus the flow rate is changed.

2.9.15 Degree of Mixing

Two types of systems are used in digestion. The plug flow system in which no mixing takes place and the completely mixed digester. Plug flow offers the advantage that there is no need for mixers, but some of the effluents must be recirculated to inoculate the feed with organisms necessary to carry out the process. The advantages of the plug flow system have been addressed by Amon (2007). Mixing offers advantages in that the substrate is kept in contact with the microbes and the temperature is kept uniformly distributed.

Mixing has three important effects on the process as it: (1) maintains uniformity in substrate concentration, temperature, and other environmental factors; 2) minimizes the formation of scum at the surface; and 3) prevents the deposition of solids on the bottom. The degree of mixing varies depending upon the feedstock and operating conditions Ahrin *et al.*, (2001) reported that there was hardly any stratification inside a KVIC digester that was fed cattle manure and that the temperature profiles were within one degree throughout the digester. He also reported increases of 8% and 11% in gas production with continuous mixing, over mixing only two hours per day in digesters using cattle manure at 55°C and retention times of six and four days. Ahrin's data would indicate that at longer detention times the effect of intermediate mixing would be minimal. Scum formation appears to be a primary function of the feed. With the addition of large amounts of fibrous materials and fats, the formation of a scum layer is likely. If the organic materials are in the scum layer, it is likely that they will not be available as feed to the organism degrading the materials to gas. Thus the gas production rates in a digester with scum layers are reduced. The reason for trying to avoid the accumulation of solids at the bottom of the tank is the reduction of detention time. Detention time is a primary factor in gas production.

2.9.16 Heating and Heat Balance

Digestion progresses more rapidly at a higher temperature therefore, is important to get the digester feed at as high a temperature as possible and to keep the heat losses to a minimum. Insulation to reduce the heat losses from a digester is very important. In examining some of the efforts in developing countries, Prasad and Sathyanarayan (1979) reported that 54% of the total heat loss was from the cover of the Indian digesters. Thus one can see that for cold climates the Indian digester with a floating metal cover is not a viable option. The materials used to insulate the digester vary from the use of dry agricultural residues (e.g. straw, hay, and corn stalks) to commercial polyurethane materials. The example was given earlier where in Turkey the digester is built into the floor of the barn. A number of heating techniques can be used in installation.

These vary from simple solar heaters placed above the digester to heat exchangers and steam injection (bubble gun) heating. Solar heat can be one of two types; active or passive. Active systems heat a portion of the feed during the day and it is then placed in the digester. Passive systems depend upon building a solar greenhouse that captures the radiant heat energy. Chongging Biogas Office (1982) reported on a comparison of a membrane digester and the Chinese digester. Since the membrane digester absorbed the solar energy the temperature was higher, and it gave a larger gas production.

2.9.17 Slurry Effluents

Slurry is discharged from the digester. The characteristics of the slurry depend upon the feedstock, the digester conditions, and the portion of the organic matter which is converted into gas. The effluents can all be handled by conventional liquid handling methods which would permit them to be transported to the field for use as a soil conditioner or to ponds for aquatic biomass production. In some areas the slurry has been separated using vibratory screens, settling tanks, or sludge centrifuges to separate the liquid and solid portions. The uses of the slurry as a soil conditioner have been described by Ward (1982). The important concept to keep in mind is that the slurry should contain all the initial nutrients contained in the feedstock. The solids will have been reduced in quantity leaving a more stabilized solid which will break down very slowly. During the digestion process, the organic nitrogen will have been partly decomposed into ammonia nitrogen. The ammonia nitrogen which is produced, while it is more available to plants, is also much easier to lose through either misapplication or drying.

2.10 Integrated Use of Biogas Technology

The key to the economic viability of BGT is maximizing the use of all its outputs, not just the energy content of the gas. The slurry contains nutrients and organic material, which may be used as animal or fish food and fertilizer. The gas can be used as an energy source for pumping water and powering motors, thereby promoting small-scale village industries and generating a cash income. The sanitation effect and use

of technology as a means of waste disposal and pollution abatement can also provide additional economic benefits. Thus, the potential of BGT can be realized when its place in the food-feed-fuel-sanitation system is better demonstrated.

2.10.1 Biogas Technology

Biogas technology is a simple technology generally utilizing waste organic materials to yield a useful fuel, methane gas. It is an indispensable source of energy in regions where the stock materials are present, and where the other conventional sources of energy are not readily available. The process of anaerobic digestion of organic materials is commonly referred to as 'biogas' because of the biological nature of gas production. David, 1986 wrote that there is considerable interest in the use and application of biogas for several reasons. First, the escalating costs of fossil fuels and the decreasing availability of renewable sources of fuel have forced many developing countries to consider the use of renewable energy technologies (RETs) for example, solar, wind, and biomass-based technologies, such as biogas, power alcohol, and gasifiers. Of these techniques, biogas has one of the lowest financial inputs per kWh of output. In addition, biogas is one of the most 'mature' in terms of years of use and number of units installed and has the potential to alleviate some of the more pressing problems in developing countries. (Acharya, 1958). Second, because biogas mimics natural environmental cycles, such nutrients as nitrogen, phosphorous, and potassium are conserved in the process and can be recycled back to the land in the form of slurry. This is in contrast to the burning biomass where most of the nutrients are lost, for example, with wood stoves and gasifiers. The application of slurry reduces the need for chemical fertilizers, such as urea and superphosphate, and in addition, enables humic materials to be recycled. This recycling preserves the physical properties of the soil and enables high agricultural productivity to be maintained (Maramba, 1978). Third, the biogas process digests animal manure and it has the potential to considerably reduce plant, animal, and pathogens. The cycle of reinfection is broken and considerable improvement in public health results. (Young and McCarty, 1969). Finally, because biogas is a clean-burning fuel, its domestic use can reduce the incidence of eye and lung problems that are commonly encountered with such smoke-producing fuels as firewood, agricultural residues, and coal (National Academy of Sciences. 1977). Furthermore, biogas is a versatile technology and can utilize a wide variety of organic feed stocks, such as animal manures, night soils, agricultural residues, aquatic plants, and organic industrial wastes. Hence, in addition to being a multifaceted technology, it has potential application to many environmental and social milieus (Reddy *et al.*, 1979).

Materials and Methods

3.1 Sampling Site

Samples of water-hyacinth were identified and collected from Ibiteinye Integrated farms ltd, Elelenwo, Port Harcourt, Rivers state, Nigeria located between latitude 4.85730 N and longitude 7.07570 E. While cow dung was obtained from an abattoir at marina junction, Eket, Akwa Ibom State situated at latitude 4.6275531 N and longitude 7.9323988E. These were then transported to the Department of Marine Biology laboratory, Akwa Ibom State University, Akwa Ibom State where the experiment was conducted.

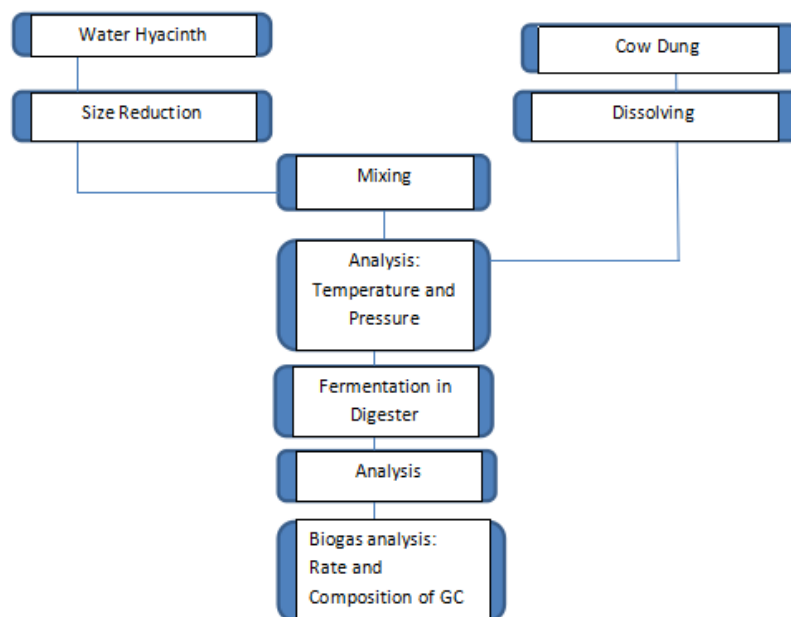


Figure 1: Experimental Steps for Biogas Production

3.2 Preparation of Sample

Water hyacinth was freshly harvested from Ibiteinye Integrated farms ltd by a worker and the experiment commenced on Monday 1st, July 2019. Samples of the plant excluding the leaves were reduced using a knife then shredded thrice with an improvised machine cassava grater (Larsen *et al.*, 1991 and Moorhead and Nordstedt, 1993) to improve its density to a higher value as well as to increase the active site for higher microbial action on it during digestion.

One (1) single 120 litres of improvised rubber cylinder can was used as an anaerobic digester. The biogas digester consists of a control valve for biogas flow regulation and a thermometer attached on the cover for temperature readings. (53.9g) of the shredded biomass and 6 kg of cow dung obtained from an abattoir at the marina junction, Eket was used. Three (3) litres of water were added for the 30 days retention time. The cow dung was mixed with water at a ratio of 3:1. The slurry of cow dung and water hyacinth was then fed to the digester for the fermentation process to begin. Experiments were carried out during the cool season and dry season (20– 40°C).

The metal cover that slides into the hydraulic joint hermetically seals the mixture. The gas was collected and stored in the gas bag. The volume of biogas was measured using an EL- STER HANDEL GMBH MAINZ volumetric meter, which has a limit of detection of less than 0.0010m₃.

The products obtained from the anaerobic digestion of water hyacinth were biogas and the compost that is removed from the digester at the end of the digestion process. The compost is an organic fertilizer having the appearance of farm manure and proven agronomical value. In the case of biogas, the digester and water container were rotated daily so that the heat is evenly distributed. The facility was raised on metal stools so that it would not be in contact with the floor and absorb cold.

3.3 Sample Analysis

For biogas, the starting material and the process (fermentation, digestion or other) usually dictate the compound list and/or method/analysis requirements. Anaerobic digestion produces biogas as a result of its degradation of organic matter. Biogas composition is mainly methane (CH_4 , 25-50%), with the remainder being nitrogen (N_2), hydrogen (H_2), oxygen (O_2), and traces of Hydrogen Sulphide (H_2S) and ammonia (NH_3). These two trace gases are responsible for the odour of the biogas and their concentration levels depend on the nature of the feedstock and process conditions. They can be removed from the biogas using scrubbers with adsorbing materials. The energy content (Lower Heating Value, LHV) of methane is 35.8 MJ/m³, and the LHV of biogas as a whole can range from 21.3 to 23.4 MJ/m³, depending on its methane content. Biogas is commonly used in Combined Heat and Power (CHP) processes to produce heat and electricity, depending on the digester and the climate of the region the facility is located at. It can be upgraded to biomethane for the production of Compressed Natural Gas (CNG) and liquefied natural gas (LNG), which have similar energy properties as fossil-fuel natural gas and can be used as transportation fuels. It is estimated that 1172 m³ of methane is equivalent to 1 tonne of oil equivalent.

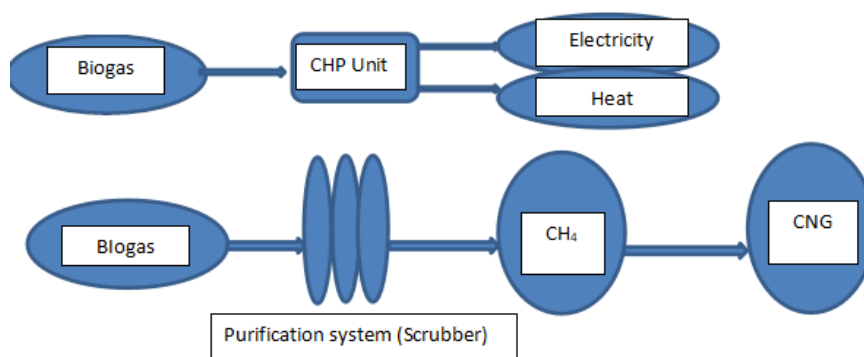


Figure 2: Biogas Products

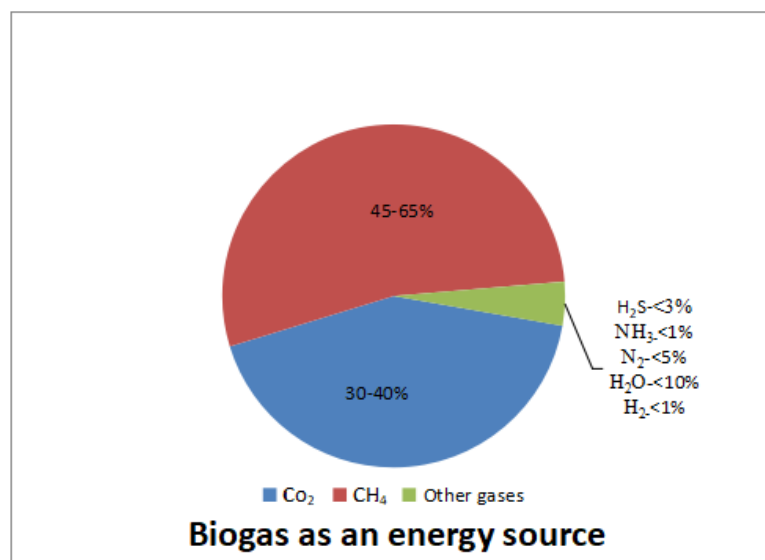


Figure 3: Biogas as an energy source

Results and Discussion

4.1 Results

The study revealed that it is possible to produce biogas from a mixture of water hyacinth and cow dung. The simplicity of the operating procedures of the digester with a scrubber and a gas bag is an advantage that can easily be replicated for household use. Biogas is a good quality fuel that can be used as a replacement for firewood and several other energy sources. The study's evaluation of production potential over a 30 days period revealed marked seasonal variations in biogas outflow.

Table 4.1: Temperature readings

| DAYS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| TEMPERATURE | | | | | | | | | | | | | | | |
| MORNING | 39 | 30 | 26 | 28 | 30 | 34 | 30 | 34 | 29 | 28 | 32 | 28 | 32 | 28 | 29 |
| AFTERNOON | 32 | 29 | 27 | 31 | 34 | 31 | 28 | 32 | 30 | 26 | 33 | 30 | 33 | 30 | 28 |
| EVENING | 30 | 29 | 27 | 26 | 32 | 32 | 28 | 30 | 31 | 27 | 34 | 29 | 34 | 29 | 27 |

| | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| TEMPERATURE | | | | | | | | | | | | | | | |
| MORNING | 34 | 28 | 40 | 30 | 28 | 30 | 35 | 30 | 31 | 30 | 34 | 35 | 34 | 35 | |
| AFTERNOON | 32 | 30 | 35 | 36 | 34 | 32 | 34 | 34 | 33 | 34 | 32 | 40 | 37 | 31 | |
| EVENING | 30 | 29 | 32 | 34 | 20 | 33 | 33 | 32 | 30 | 37 | 31 | 30 | 28 | 31 | |

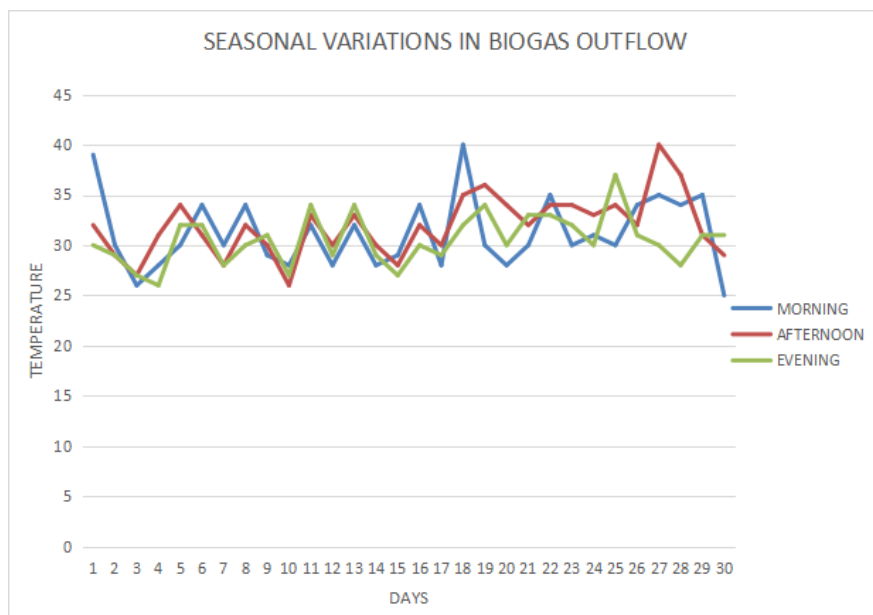


Figure 4: Graph showing Temperature Variations in Biogas Outflow

4.2 Discussion

The basis of this study was to explore the possibility of producing biogas with water hyacinth and using it, instead of firewood for cooking which has been proven, as confirmed by certain authors (Chanakya *et al.*, 1993; Kivaisi and Mtila, 1998; Singhal and Rai, 2003; Kumar, 2005). In this study, Biogas outflow was clearly related to seasonal variations in temperature. For the same retention time, the total volume of biogas obtained during the warm season was greater than that obtained during the cool season.

The biogas produced was flammable, combustible with odor, and on combustion produced blue flame indicating the presence of methane. This odor can be attributed to the presence of other gases such as H_2S . The study thereof revealed that the higher the dilution level and presence of cow dung, the higher the biogas production yields. Thence, the production of biogas from water hyacinth can serve as a sustainable control measure for managing weed proliferation. Additionally, the slurry can serve as a rich fertilizer for crops.

4.2.1 Observation

- Soluble gases were dissolved in the water and since methane does not dissolve in water it is passed into the gas bag.
- When the gases passed from the digester into the scrubber they caused some bubbles.
- An increase in pressure led to expanding of the digester
- Bubbles first appeared when the temperature was at $40^{\circ}C$ and gas production started.

4.2.2 Limitations

- With this project, the main constraint, once the facility was set up, was to procure the water hyacinth outside the state.
- There were gas leakages that could lead to reduction of the gas since they were made by hand.
- The experiment was greatly affected by the weather because it needed a high temperature for gas production resulting in a smaller quantity of gas. (Low gas production during cool season)

- The experimental set up wasn't available so it had to be made from scratch which resulted in patching some areas with adhesives.

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The study has shown that digesters are able to produce biogas from a mixture of water hyacinth and fresh rumen residue (Cow dung) to meet collective needs in cooking energy. The facility's yield of 1 kg of gas was collected. Although the yields have been quite satisfactory, they can be improved by applying the appropriate pretreatments. Promoting the use of biogas is a means of dealing with organic wastes and addressing mankind's energy needs. Using the water hyacinth as a substrate for the production of biogas is an advantageous control strategy because it permits a "productive fight" against the plant's invasion. The stock, which is available in a given space and time, is renewable, and all of the harvested plants are replenished within a growing season. The digester is just a small part of the whole system, which encompasses, on the one hand, the harvesting and processing of the raw material (water hyacinth, plant residues, organic urban waste, etc.) and on the other, the management of the finished products: biogas and organic fertilizer. The successful popularisation of biogas is more than just a question of technological approaches focused on engineering. It must also be in line with a safe integration of the weed so as to maximize its potential.

5.2 Conclusion

Biogas production results in two products - biogas and digestate. Anaerobic digestion involves biogas production via the microbial degradation of organic compounds in the absence of oxygen. It reduces the bulk of organic matter to be disposed, generates digestate rich in nutrients that can be of agricultural value, and produces biogas rich in methane which can be used as fuel directly or can be converted to Compressed Natural Gas (CNG) and Liquefied Gas (LNG).

5.3 Recommendation

On the basis of the findings and the conclusion of the study, the following recommendations are made:

5.3.1 Minimization

- To promote the use of the water hyacinth, the supply constraints can be resolved by making raw materials available on school grounds.
- Apply known technical solutions including insulation, solar tent, solar heated feed water, and compost around digester, add urine/water hyacinth, build digester under shed, and heat with biogas or engine exhaust heat.

5.3.2 Further research work should be carried out to investigate:

- The quantity, quality and composition of biogas produced vary from one animal waste to the other. So, also biogas produced from agricultural waste varies from that of animals. For this reason, investigation of the quantity, quality and composition of biogas produced from agricultural wastes is imperative.
- Issues involving the recovery of biomass energy and the decisions concerning the promotion of biogas technology in order to replace firewood should be further researched so as to be employed on a large scale basis. Finding a reliable alternative to the excessive dependence on electricity continues to pose a challenge that the promotion of methane fermentation technology might help resolve.
- The creation of a biogas market, led by private contractors and run by youths, which will most likely contribute to the popularization of biogas technology for domestic purposes and job creation.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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