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EXPERIMENTAL INVESTIGATION ON BIOGAS PRODUCTION FROM ANAEROBIC CO-DIGESTION OF WATER HYACINTH AND FISH WASTE

Yasini Nalinga[1] , Isack Legonda[2]

[1]Department of Sustainable Energy Science and Engineering, Nelson Mandela African Institution of Science and Technology, P. O. Box 447, Arusha-Tanzania

[2]Department of Mechanical and industrial Engineering, The University of Dar-es-Salaam, P. O. Box 35131, Dar-es-Salaam-Tanzania.

Abstract

Co-digestion of various wastes and biomass feedstock has been shown to improve the digestibility of the materials and biogas yield. In this study, the co-digestion of water hyacinth and fish waste was studied at different mixing proportions. The anaerobic digestion was carried out in batch digester reactors sized 500 ml and were charged to 10 % of total volume. Co-digestion was conducted for a retention period of 21 days in mesophilic temperature ranging 25.3 °C to 33.4 °C. The research revealed that the highest biogas production was observed from the combination of FW:WH, at 1:2 ratio. The maximum biogas recorded was 0.56 liters with composition of 73.3 % CH_4. Furthermore, the water hyacinth also recorded 0.46 liters with the composition of 70 % CH_4 which suggest economical feasibility. The overall results showed that blending water hyacinth with fish waste had significant improvement on the biogas yield.

Keywords: co-digestion, anaerobic digestion, biogas, water hyacinth, fish waste

1 Introduction

The idea of replacing wood fuel and petroleum oils by alternative fuels such as biogas has encouraged Tanzania Government to set up biogas programs. Biogas is much more convenient and clean to use than traditional fuels, such as fire wood and charcoal, that is why Tanzania Domestic Biogas Programme (TDBP) was designed to disseminate in Tanzania 30,000 biogas plants by the year 2017 [1] so as to empower rural communities. However, there seems to be insufficient knowledge on the conversion of substrates other than the traditionally used cow dung [2]. Currently there is a need of looking and utilizing some other types of biomass resource available in greater quantity as a feedstock to biogas production [3].

Fish waste and water hyacinth cause adverse environmental impacts and affect the health of Lake Victoria side communities. The feedstock can be utilized and converted to biogas production through the process known as co-digestion. Co-digestion is the simultaneous digestion of more than one type of waste in the same unit. Advantages include better digestibility, enhanced biogas production and methane yield arising from availability of additional nutrients [4].

Water hyacinth grows up to 2 meters thick which can reduce light and oxygen in the water, change water chemistry, affect flora and fauna and cause significant increase in water loss due to evapotranspiration [5]. It also causes practical problems for marine transportation, fishing and at intakes for hydropower and irrigation schemes [6]. It is now considered as a serious threat to biodiversity [7]. Therefore, there is a need to manage its spread through suitable control measures. However, the fact remains that the water hyacinth has successfully resisted all attempts of its eradication by chemical, biological, mechanical or hybrid means [8]. Water hyacinth has attracted the attention of scientist to use it as a potential biomass as it is rich in nitrogen, essential nutrients and has a high content of fermentable matter [9].

Water hyacinth and other invasive aquatic weeds once established are very difficult to manage and total eradication is often not possible [10]. There is greater discrepancy among the policy makers, environmental agencies and research scientists on the way to control this invasive species and practical benefits that can be obtained [11]. Various studies done on the weed controls in Lake Victoria shows that manual removal of water hyacinth has proved to be useful in controlling small infestations [12]. One of the solutions in order to maintain the water systems ecology balanced and promote environmental management is to harvest the aquatic weeds manually and manage fish waste disposal. Subsequently water hyacinth and fish wastes can be utilized for biogas production thus promote manually harvesting of hyacinth and solve fish waste disposal problem.

Water hyacinth is the plant termed as a reservoir for both energy and nutrients [13]. Harvesting and used as a feedstock for anaerobic digestion could allow for both energy and nutrients to be captured in a controlled manner which would ensure their removal from the reservoir system and value added re-use [14].

In Tanzania biomass in the form of wood fuel and charcoal accounts for more than 90% of the national energy supply while domestic sector is the largest consumers [15]. It is therefore, obvious that biomass represents an important part of the raw materials necessary for the satisfaction of energy use in many developing countries including Tanzania. It is hypothesized that if small household's biogas digesters can be developed to utilize water hyacinths and fish wastes as a replacement for biogas production, some wood and charcoal users might start using biogas for cooking purpose instead continuing using wood which has proved to affect environments.

The aim of the research is to investigate the potentials by recovering bio energy from anaerobic co-digestion of water hyacinth and fish waste as feedstock for biogas production due to greater nutrients availability and potential of their conversion into biogas.

2. Literature review

2.1 Anaerobic Digestion

Anaerobic digestion (AD) is a microbiological process of decomposition of organic matter, in the absence of oxygen, common to many natural environments and largely applied today to produce biogas in airproof reactor tanks, commonly named digesters. A wide range of micro-organisms are involved in the anaerobic process which has two main end products: biogas and digestate [16]. Biogas is a combustible gas consisting of 50-70 % methane, 30-50 % carbon dioxide and small amounts of other gases and trace elements and has a calorific value of 21-24MJ/m^3 [17]. Digestate is the decomposed substrate, rich in macro- and micro nutrients and therefore suitable to be used as plant fertilizer.

The digestion process begins with bacterial hydrolysis of the input materials to break down insoluble organic polymers such as carbohydrate [18]. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these organic acids into acetic acid, along with additional ammonia, hydrogen and carbon dioxide [19]. Methanogenic bacteria then convert acetic acid and hydrogen to methane and carbon dioxide. There are three key biological and chemical stages of anaerobic digestion, Acidogeneses, Acetogenesis, and Methanogenesis [20].

However, there are several conditions and variables that must be applied in order to obtain a proper breakdown of the organic compounds. The operating parameters of the digester must be controlled so as to enhance the microbial activity and thus increase the anaerobic efficiency. These are temperature, pH, retention time and carbon to nitrogen (C: N) ratio.

The anaerobic digestion process can take place at different temperature that can be divided into three temperature ranges namely Psychrophilic (below 25^{o}C), Mesophilic (25^{o}C-45^{o}C) and Thermophilic (45^{o}C-70^{o}C). There is a direct relation between the process temperature and the hydraulic retention time (HRT) as shown in the Table 1.

Table 1: Thermal stage and typical retention times

Thermal stage	Process temperatures	Minimum retention time
Psychrophilic	<20 ^{o}C	70 to 80 days
Mesophilic	30 to 42^{o}C	30 to 40 days
Thermophilic	43 to 55^{o}C	15 to 20 days

The pH value is the measure of acidity/alkalinity of a solution (respectively of substrate mixture in the case of AD).

The pH value of the AD substrate influences the growth of methanogenic microorganisms and affects the dissociation of some compounds of importance for the AD process (ammonia, sulphide, organic acids) [20]. Experience shows that methane formation takes place within a relatively narrow pH range from 5.5 to 8.5, with an optimum interval between 7.0-8.0 for most methanogens. Acidogenic microorganisms usually have lower value of optimum pH severely inhibited if the pH-value decreases below 6.0 or rises above 8.3. the solubility of carbon dioxide is therefore higher than in mesophilic ones, as dissolved carbon dioxide forms carbonic acid reaction with water as reported by [21].

Retention time is the time used to degrade the organic matter to a specific degree. The retention time varies with process parameters, such as process temperature and waste composition. The retention time for waste treated in a mesophilic digester ranges from 10 to 40 days and 12-14 days for thermophilic digester as reported by [22].

On the other hand, the relationship between the amount of carbon and nitrogen present in organic material is represented by the C: N ratio. Optimum C: N ratios in anaerobic digesters are between 20 and 30. A high C: N ration is an indication of a rapid consumption of nitrogen by the methanogens and results in a lower gas production. Besides, a lower C: N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria [21].

2.2 Co-digestion

Co-digestion is the simultaneous digestion of more than one type of waste in the same unit. Advantages include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing. Studies have shown that co-digestion of several substrates, for example, banana and plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield by as much as 60 % compared to that obtained from single substrates [23].

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3 Material and methods

3.1 Sample Preparation

Samples of water hyacinth (WH) were taken from Lake Victoria, Mwanza and fish wastes (FW) were collected from ferry fish market in Dar es Salaam city. Fish waste consisted of offal's and gills.

3.2 Inoculums source

Anaerobic inocula used for digester start up was taken from Vingunguti slaughtering house in Dar es Salaam consisted of small intestine cow dung and blood with the ratio of 1:1

3.3 The principle of experiment

The principle of the biogas production of the mixture of feed stocks used in this study is shown in Figure 1. 30 gm of feedstock blend was mixed with 300 ml of inoculums and 150 volume of water. The experiment was carried under mesophilic temperature. The increase in gas chamber pressure in the test digester resulting from the production of carbon dioxide (CO_2) and methane (CH_4) was measured.

On the other hand, the amount of microbiologically produced carbon is calculated from the net gas production and the net inorganic carbon (IC) formation in excess over blank values (BS EN ISO 11734:1999).

The net mass of carbon produced as gas in the gas chamber from the test feedstock was determined by equation (1):

$$m_{c,g} = \frac{12000\,x(0.1)x(\Delta p V_{gc})}{RT} \quad (1)$$

Where

$Mc_{,g}$ is the mass, in milligrams, of net carbon produced as gas in the headspace

Δp is the mean of the differences between initial and final pressures, in millibars, in the test vessels minus those in the blank vessels

V_{gc} is the volume, in litres, of headspace in the vessel

0.1 is the conversion factor for both Newton per square metre to millibar and cubic metres to litres

R is the molar gas constant [8,314 J/ (mol·K)]

T is the incubation temperature, in kelvins

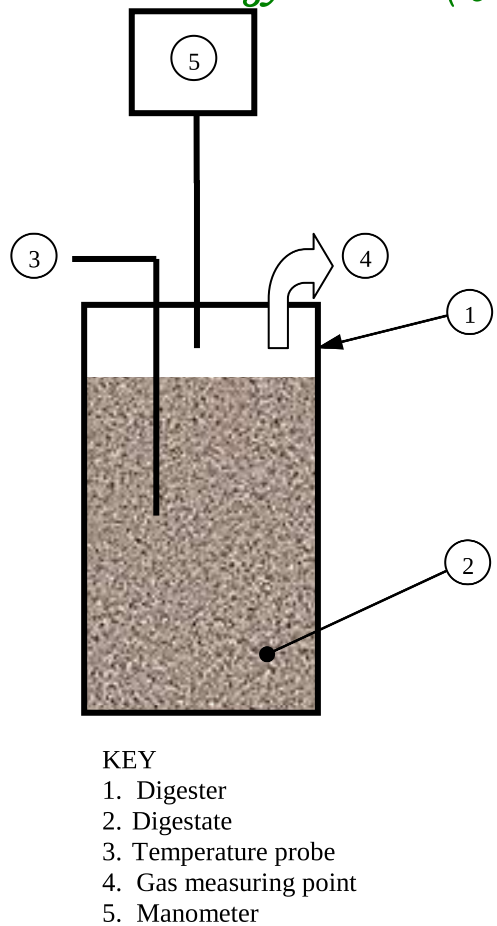

Figure 1. Schematic diagram of the experimental layout for biogas production

3.3.1 Experimental Materials

The feedstock used in this study was the mixture of water hyacinth and fish waste, at the ratio of 1:1, 1:2, 2:1, as well as water hyacinth, fish waste and inoculum alone, giving the total of six digested sample. Water hyacinth leaves were collected from different growth stage and allowed to be dried under the sun for 2 months, followed by crushing into very fine particles (powder) as shown in the Plate 2, after which they were dried in an oven at 60 °C for 4 hours while the fresh fish waste were collected and blended by using electrical kitchen blender and stored at -20 °C.

(a) Water hyacinth

(b) Fish waste

Fig 2: Feedstock samples for (a) water hyacinth and (b) fish waste

3.3.2 Experimental set up

The experimental set up for the digested feedstock consisted of 6 bioreactors for each substrate. A control bioreactor containing only cow dung (inoculum) without waste was included and the biogas produced was subtracted from those with substrate. In the co-digestion experiments the mixtures of feedstock in varying proportions as described in Section 3.3.1. The volume of inoculum and water were kept constant at 450 ml for all digesters.

The schematic diagram of the experimental set-up of the biogas production is presented in the Figure 3. The experimental set up is comprised of a 6 digester reactors with each total volume of 500 ml and working volume of 450 ml. The temperature in the digester was measured on daily basis using YC-747UD thermometer datalogger with K-Type thermocouples. The Pressure gauges were employed for monitoring biogas production while bucket with sand acted as thermal insulation to control temperature inside the digester reactors.

(a) Digesters

(b) Experimental assembly

Fig 3: Setup for (a) Digesters and (b) Experimental assembly

4 RESULTS AND DISCUSSIONS

4.1 Material Characterization

4.1.1 Characterization of the feedstock

Figure 2 shows the BOD test for feedstock used in this study. It can be seen from the figure that the BOD for water hyacinth was higher compared to fish waste. Moreover, the BOD trend for water hyacinth showed increasing steadily within the first and last two days while the fish waste was vice versa. The observed higher BOD for water hyacinth could be attributed to the greater amount of biodegradable and fermentable matter available in the substrate. Another attribute is the low concentration of volatile fatty acid (VFA) in water hyacinth which stabilize pH of the substrate as reported by [24]. This finding suggests that water hyacinth is much more potential feedstock for biogas production. Previous study by [25] also has shown similar findings.

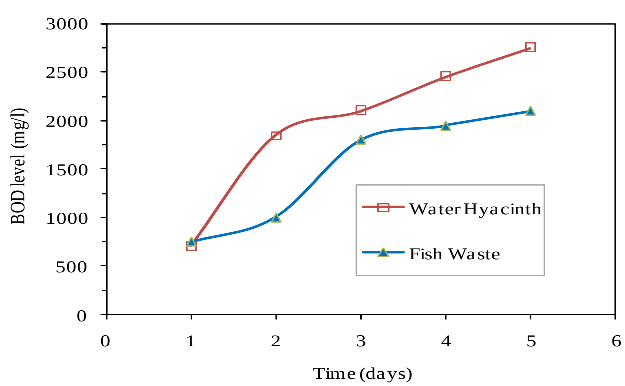

Figure 1: BOD test for the main feedstock (water hyacinth and fish waste)

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4.1.1.2 Solids Analysis

Total solids are the sum of suspended solids and dissolved solids. Total solids analysis is important for assessing anaerobic digester efficiencies. The total solids are composed of two components, volatile solids and fixed solids. The volatile solids (VS) are organic portion of total solids (TS) that biodegrade anaerobically. Total solids and Volatile solids for water hyacinth and fish waste were determined by the oven-drying and ignition method, respectively according to standard methods, American Public Healthy Association, (1995). The solids analysis from water hyacinth and fish waste were analyzed as shown in the Table 2 below.

Table 2 : Results for TS and VS for the feedstock samples

Feedstock Samples	% TS	% VS as % TS
Water Hyacinth	27.76	80.9
Fish Waste	32.2	55.3

4.1.1.3 Carbon to Nitrogen ratio of the feedstock

Nitrogen content as determined using kjeldahl digestion method from the water hyacinth and fish waste recorded total nitrogen content of 2.54 % and 5.44 % respectively. Total carbon was determined by the dry combustion method as previously described by [26] and recorded organic carbon content of 42 % for water hyacinth and 53 % for fish waste. Thus, the C: N ratio for water hyacinth was 17:1 and 10:1 for fish waste. These results are in good agreement with the analysis done by [27] reported that water hyacinth is rich in nitrogen content up to 3.2% and have C:N ratio of 15:1.

4.2 Cumulative Biogas Production

Figure 3 shows cumulative biogas production from different feedstock ratios. It can be seen from the figure that the highest biogas production was observed from the combination of fish waste and water hyacinth at 1:2 ratio which recorded a maximum of 0.56 liters followed by water hyacinth 0.46 liters, and combination of fish waste to water hyacinth in 2:1 ratio, 0.40 liters. This could be caused by achieving higher anaerobic digestion temperature in the combination of the FW: WH, 1:2 ratio (27°C to 33.4°C) as shown in table 3, compared to other reactors since the degradation rate of substrates goes up with temperature rises as stated by [28].

In this study the C: N ratio for the FW: WH at 1:2 ratio was calculated to be 15:1. This value is within the accepted range 10:1 to 30: 1 [29, 30]. For optimum biogas production it is desirable to promote the growth of bacteria and inhibit the generation of ammonia and VFAs in the digester.

The combination of substrate and inocula mixed with blood probably contain balanced concentration of total nitrogen as highlighted in section 2.4.3. Also trace metals provide higher concentration of micronutrients which act as microbial agents responsible for the anaerobic digestion as reported by [31]. [32] further observed that the combination is rich in high content of fermentable and biodegradable matter as shown to BOD test done for the feedstock.

The pH level of the substrate also constitute to the biogas production as it was close to neutral (6.8) as stated by [33]. The lowest value of total biogas production was observed from the cow dung (inoculums) alone with the value of 0.30 liters. This might be due to low total solid content (TS) less than 8 % and less availability of nutrients in the substrate for maintaining the growth of anaerobic bacteria as reported in the literature [2, 34].

[35] observed that dry water hyacinth produced greater amount of biogas production. From this there is clear evidence that when the water hyacinth as a biomass feedstock is increased there is also increase of total biogas production and vice versa.

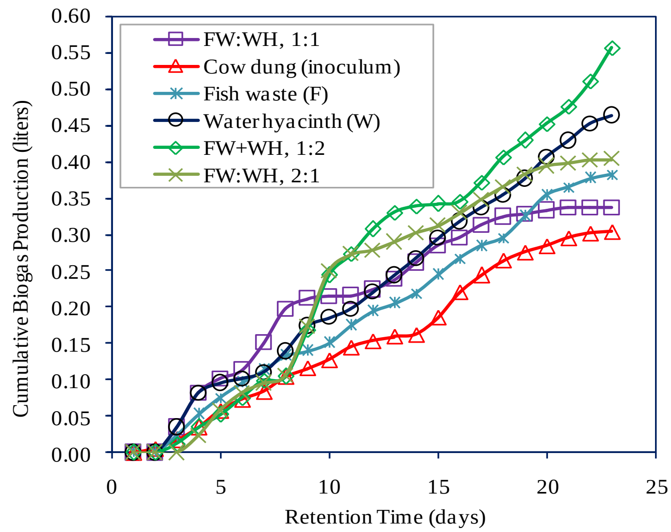

Figure 2: Cumulative biogas production as a function of time for various substrate ratios

4.3 Daily Temperature measurements

Figure 4 shows the different daily temperature recorded in each reactor by using K-type temperature data logger with thermocouples. The trend is almost similar in each reactor and shows the operating temperature varying from the minimum temperature recorded of 25.3 °C to the maximum temperature of 33.4 °C with a retention time of 21 days. This agrees with [36], who concluded that biogas production in anaerobic digestion operated at mesophilic temperature range between 20 °C and 35 °C and takes a retention time (days) of 15 to 30 days.

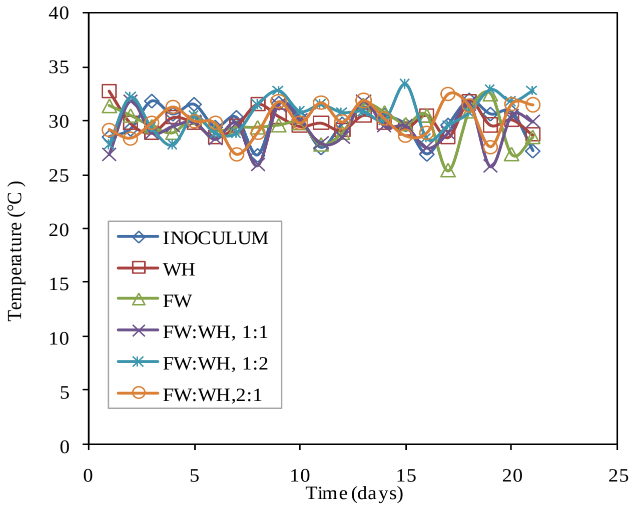

Figure 3: Daily temperature profiles

4.4 Biogas Composition

Figure 5 shows methane concentration from different feedstock proportions. The maximum methane concentration from cow dung feedstock was 60 % while for FW: WH ratios of 1:1, 2:1 and 1:2 were 63 %, 65 % and 73.3 % respectively. Moreover, the result from water hyacinth and fish waste showed that methane concentrations were 66 % and 70 % respectively. There are several explanations on these results.

The observed high methane concentration from water hyacinth than those of fish waste can be linked to the high generation of methanogenetic bacteria as confirmed through BOD analysis presented in Figure 2. This finding suggests that water hyacinth promote favourable condition for methanation process. Furthermore, the observed optimal methane concentration from FW: W ration of 1:2 could be due to catalytic effect attributed by trace element from fish waste. In general, the results suggest that both fish waste and water hyacinth can be utilized as feedstock for biogas production.

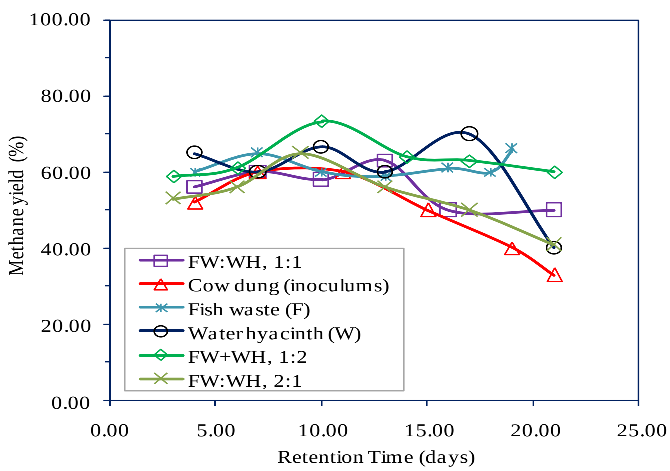

Figure 4: **Methane contents at different feedstock**

4.5 Conclusions

The study has shown that anaerobic co-digestion of fish waste and water hyacinth is a viable and feasible process for large biogas plants. Moreover the study suggests that optimum fish waste to water hyacinth ratio is 1:2. On the other hand, the water hyacinth showed high biogas production compared with fish waste. In general, both fish waste and water hyacinth are potential feedstock for biogas production.

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Biographies

YASIN S. NALINGA received the Bachelor degree in Mechanical Engineering from the Mbeya University of Science and Technology and is now pursuing the Msc degree in Sustainable Energy Science and Engineering in Nelson Mandela African Institution of Science and Technology under the supervision from Dr. Isack Legonda from the University of Dar es salaam. Author may be reached at nalingay@nm-aist.ac.tz