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PROSPECT OF SUSTAINABLE ENERGY (BIOGAS) GENERATION FOR USE IN UNIVERSITY OF UYO CAFETERIA

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ABSTRACT

Purpose: This study explored the potential of biogas production from wastes generated in University of Uyo, as an alternative source of energy for the University Cafeteria.
Design/methodology/approach: Three major wastes were collected from University of Uyo Annex Campus, consisting of cow dung, poultry litter and kitchen wastewater (from the University Cafeteria). As a quantitative research, the study adopted an experimental design that involved the treatment and use of the collected wastes as substrate for digestion and generation of biogas.
Findings: The experimental procedure of co-digesting 11.5kg of combined cow dung, poultry litter and kitchen wastewater, resulted in the production of 8500ml of raw biogas. Further, to obtain pure methane from the raw biogas, impurities such as carbon dioxide and hydrogen sulphide were removed using two chemical scrubbing solutions, comprising of ordinary water with sodium hydroxide, and ferric chloride with sodium hydroxide. Test for combustibility of the purified gas indicated a positive result, as the obtained gas supported burning.
Research Limitations/Implications: A bigger anaerobic digester would have been used to produce larger volumes of biogas; however, this requires more funds to execute.
Practical Implications: With the adoption of this technology in larger scale, landfilling of University of Uyo wastes would be greatly reduced and possibly eliminated. Also, if on a pilot scale, 8,500ml of raw biogas was produced from 11.5kg of combined waste, then there is need to explore the large amount of organic waste that are readily available within septic tanks or sewage systems in the University.
Originality/value: As there is currently no unit within the university where wastes are converted into renewable energy, the support and operation of this technology in larger scale would highly enhance the sustainability status of University of Uyo.

Keywords: Anaerobic digestion; biogas; cow dung; kitchen wastewater; methane; poultry litter.

1. INTRODUCTION

In contemporary times, increasing concern for environmental health, eco-friendly waste management and sustainable energy production, constitute the focus of many

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trade bodies, regulatory agencies and countries of the world. Energy, which is a driver of economic growth, is obtained from various primary sources that are not limited to coal, petroleum, nuclear, etc., but also incorporates renewable sources from wind, solar and biomass. However, the most widely used sources are the non-renewable fossil fuels that account for more than 80% of global primary energy consumption (Awwad & Mohammed, 2007), with their attendant environmental pollution.

Nigeria is not left out of such immense dependence on fossil fuel. A country endowed with primary energy resources with a record of the world's tenth largest reserve of crude oil, and an estimate of about 36 billion barrels or circa 4.896 billion tonnes of oil equivalent in 2006 (Dayo, 2008). As Nigeria is a highly populated country in Africa, it has significant resources of organic waste. Industrialization, growing urbanization, and agricultural activities have resulted in environmental pollutions from industrial, municipal and agro-allied waste. This explains why it is now critical not only to focus on the economic use of the existing limited resources, but to identify new technologies and renewable resources that explore the potentials of the energy inherent in waste, in order to minimize the increasing energy demand.

Further, biogas technology has not been widely adopted as an energy or economic strategy in many organizations and institutions in Nigeria (Ogwueleka, 2009). An institution like the University of Uyo is no exception. In the University, there has been great concern over the rising environmental pollution and fluctuating power supply. The Annex Campus, being one of the Campuses of the institution, has significant amount of wastes. Some of these wastes include municipal solid waste (MSW), such as large amount of papers, polythene bags, plastics, sewage waste, animal waste (cow dung) and wastewater from hostels and the university cafeteria. These wastes (especially cow dung from cattle left to graze within the campus) are often unsightly (see Figure 9.1). While there is need to foster a clean environment for a conducive academic learning around the Campus, more proactive measures can be put in place to ensure environmental sustainability, by utilizing these wastes as a source of energy for facilities in the University. This research is carried out to explore the possibility of biogas generation as an alternative source of energy in the University of Uyo. This will help build a body of knowledge in biogas energy generation and further create awareness of the need for sustainable energy sources in the University of Uyo and beyond.

1.1. Aim and objectives

The aim of this study is to develop a biogas system that will generate clean energy as an alternative source of energy for the University of Uyo Cafeteria. The following objectives are set to achieve this aim: To:

i. develop an anaerobic reactor for biogas production.
ii. use cow dung, poultry litter and kitchen wastewater as substrate for biogas production.
iii. determine the volume of biogas produced.
iv. scrub the raw biogas.
v. carry out a flammability test on the produced biogas

2. REVIEW OF RELATED LITERATURE

With a current population growth rate of 2.03% to 7%, energy consumption and waste generation in Nigeria is expected to soar over the next few years (Amber, Kulla, & Gukop, 2012). The average waste density currently ranges between 280 to 370 kg/m³, with waste generation rates ranging from 0.44 to 0.66 kg/capita/day (Ogwueleka, 2009). In a research by Amber, Kulla, & Gukop (2012), samples of 10 kg each of raw Municipal Solid Waste (MSW) were taken randomly from dump sites whose sources were generated from different activities in some selected state capitals representing each of the six geopolitical zones of Nigeria. The collected waste samples revealed high proportion of polythene waste from sachet drinking water, popularly known as 'pure water', and shopping bags with calorific values averaging 14.89MJ/kg (see Table 4.1 for energy contents of assessed waste materials). Additionally, on the basis of incinerating 1500 ton of MSW/day, with an average calorific value of 17.23MJ/kg and conversion efficiency of 25% and 49%, the thermal treatment of MSW resulted in the production of 700 kWh of electricity per ton of MSW combusted. In practice, about 65 to 80% of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power, via steam turbine generators (with typical conversion efficiency of about 30%) (Amber, Kulla, & Gukop, 2012).

Table 4.1: Energy content of MSW

Components	Energy content (MJ/kg)
Organic / food	11.59
Cardboard	11.033
Plastics	14.89
Polyethene	46.5
Textile	9.27

Source: (Amber, Kulla, & Gukop, 2012)

2.1. Anaerobic digestion

Anaerobic digestion (AD) is a biochemical process that converts a variety of organic matter using naturally occurring microorganisms under oxygen depleted conditions, to produce a gaseous mixture mainly composed of methane and carbon dioxide, known as biogas (Botheju & Bakke, 2011). As noted by Botheju & Bakke (2011), anaerobic digestion occurs naturally inside landfills, due to the presence of large amounts of organic waste and scarcity of oxygen. This emits a biogas normally composed of about 50% Methane, 50% Carbon IV Oxide, and trace amounts of other gases (Environmental and Energy Study Institute, 2009). The anaerobic digestion (AD) process can also be engineered to occur in a dedicated facility known as an anaerobic digester, primarily a closed vessel kept with a culture of microbes, fed regularly with digestible (organic) matter (Botheju and Bakke, 2011). Anaerobic digesters are typically large or small reactors constructed of either concrete, rubber or steel. The volume of the reactor depends on the volume of waste to be processed in the system. As with most conventional digesters, a retention time of 20 - 30 days is required to convert solid manure into methane (Sharvelle & Loetscher, 2011). According to Sharvelle & Loetscher (2011), in a simple digester, using steel, plastic or concrete, the configuration is the tank / chamber with an inlet for waste input, outlet for digestate removal as fertilizers, and a gas valve outlet for gas collection and further processing.

2.1.1. Anaerobic digestion of animal waste

Animal manure is a valuable source of nutrients and renewable energy. However, most of the manure are left to decompose in the open, settle on river beds or float on water, thereby constituting significant environmental hazards. According to Alvarez & Liden (2009), the large amounts of animal manure and slurries produced today by the animal breeding sector as well as the wet organic waste streams, represent a constant pollution risk with negative impacts on the environment. Also, air pollutants emitted from manure, consisting of methane, nitrous oxide, ammonia, hydrogen sulphide, volatile organic compounds and particulate matter, could cause serious environmental hazards and health problems (Alvarez & Liden, 2009). In some places, livestock waste is recovered and sold as a fertilizer or simply spread onto agricultural land. However, the introduction of tighter environmental controls on odour and water pollution heralded some form of waste management, which provides further incentives for biomass-to-energy conversion (Zafar, 2018). According to Steinfeld et al. (2006), the animal production sector is responsible for 18% of the overall greenhouse gas emissions, measured in Carbon IV Oxide equivalent, and 37% of the anthropogenic methane, which has 23 times the global warming potential of Carbon IV Oxide. Furthermore, 65% of anthropogenic Nitrous Oxide and 64% of anthropogenic ammonia emission, originate from the worldwide animal production sector (Steinfeld et al., 2006).

Animal wastes include livestock manures from cow dung, sheep, pig, goat, fowl and other domesticated animals. Abubakar & Ismail (2012) investigated the effectiveness of cow dung for biogas production. The average cumulative biogas yield and methane content observed was 0.15 L/kg volatile solid (VS). Further, Alvarez & Liden (2009) studied biogas production through anaerobic digestion in farm-scale units under mesophilic conditions. The results suggest that digesting a mixture of llama-cow-sheep manure at low temperature of between 291–298K (equivalent to 17.85–24.85°C), yielded methane in the range 0.07–0.14 m^3/kg. Also, in a research conducted by Recebli, Selimli, Ozkaymak & Gonc (2015), biogas production potential from bovine animal and fowl manure were separately studied. 350 kg bovine animal manure blend (175 kg manure +175 kg water) and 375 kg fowl manure blend (50 kg manure+325 kg water) were separately digested. Then the biogas production rates were evaluated and compared for the two processes. Results showed that daily 6.33m^3 and 0.83m^3 biogas productions were obtained from fermentation of bovine animal manure and fowl animal manure respectively.

2.1.2. Co-digestion of substrates

Co-digestion of animal manure with various biomass substrates increases the biogas yield and offers a number of advantages, including the management of manure and organic wastes, and mitigation of greenhouse gas (GHG) emissions (Holm-Nielsen, Al Seadi, & Oleskowicz-Popiel, 2009; Van Nes & Nhete, 2007). In co-digestion of plant material (like paper) and organic manures (like bird litter and cow dung), organic manures provide buffering capacity and a wide range of nutrients, while the addition of plant material with high carbon content, balances the carbon to nitrogen (C/N) ratio of the feedstock, thereby decreasing the risk of ammonia inhibition (Zafar, 2018). According to Zafar (2018), animal manure has a Carbon – Nitrogen ratio of 25:1, and is considered ideal for maximum gas production. Solid concentration in the feed material is also crucial to ensure sufficient gas production, as well as easy mixing and handling. Thus, the gas production per digester volume can be increased by operating the digesters at a higher concentration of solids (Zafar, 2018).

2.2. Scrubbing: removal of impurities from biogas for production of pure methane

Scrubbing in biogas production, also known as absorption is the process of removing impurities or contaminants from raw biogas, in order to enhance its combustibility. Such impurities majorly include Hydrogen Sulphide (H_2S), Carbon (IV) Oxide (CO_2), Water (H_2O), etc., although biogas is primarily composed of Methane (CH_4) and Carbon (IV) Oxide (CO_2) (Rincón, Heaven, Banks & Zhang, 2012). The presence of each of these contaminants portends varied negative aftermaths. Combustion of biogas containing H_2S produces Sulfur Dioxide (SO_2), which when combined water vapor, produces Sulfuric acid (H_2SO_4), and when exposed to the environment, causes acid rain; whereas, the presence of CO_2 and water vapor in biogas, leads to circa 80% combustion inhibition (Shah, Nagarsheth & Acharya, 2016). As noted by Shah, et al. (2016), removal of these impurities in biogas, raises the methane content of the biogas, and primary methods of scrubbing biogas include water and chemical scrubbing; other methods like cryogenic separation, membrane pressure and swing adsorption, involve higher installation costs.

3. Research Materials and Methods

The raw materials, digester description and experimental procedures adopted for this study are covered in this section.

3.1. Raw materials

Cow dung littered on the University of Annex campus roads, poultry litter from the Faculty of Agriculture poultries and kitchen wastewater from the University Cafeteria were collected for co-digestion. These were differently treated and used as substrate for co-digestion and production of the Biogas.

3.2. Digester description

A biogas chamber made of portable plastic barrel, having a height of 0.6m that bears a slurry capacity of 20kg was constructed to be used for this experiment (see Figure 9.2). The inlet pipe (25mm dia. PVC) serves as the means of introducing the substrate for digestion; whereas, the residue is evacuated through the outlet device made up of 25mm diameter PVC pipe at the bottom. Raw biogas collection was through pressure developed within the reactor that forced the gas out through a 10mm diameter flexible rubber pipe with a valve at the top for delivery into the collection unit.

3.3. Experimental procedure

In this study, potential for biogas generation was investigated using a batch process, in which the slurry was added once in the digester for the whole duration of the process. The experiment was carried out by co-digestion of the raw materials consisting of cow dung, poultry litter and kitchen wastewater (Figure 9.3 & 9.4).

Pre-treatment was carried out for cow dung and the poultry litter at 90oC for 8hours. Having each mixed with some quantity of the kitchen wastewater, the cow dung weighed

3.5kg before, and 3.2kg after treatment. The bird litter weighed 3.5kg before, and 3.1kg after treatment. Both were thoroughly mixed using 5kg of the kitchen wastewater to attain a sufficient slurry before feeding into the reactor. A summary of the experimental procedure is revealed in the flow chart below (Figure 5.1).

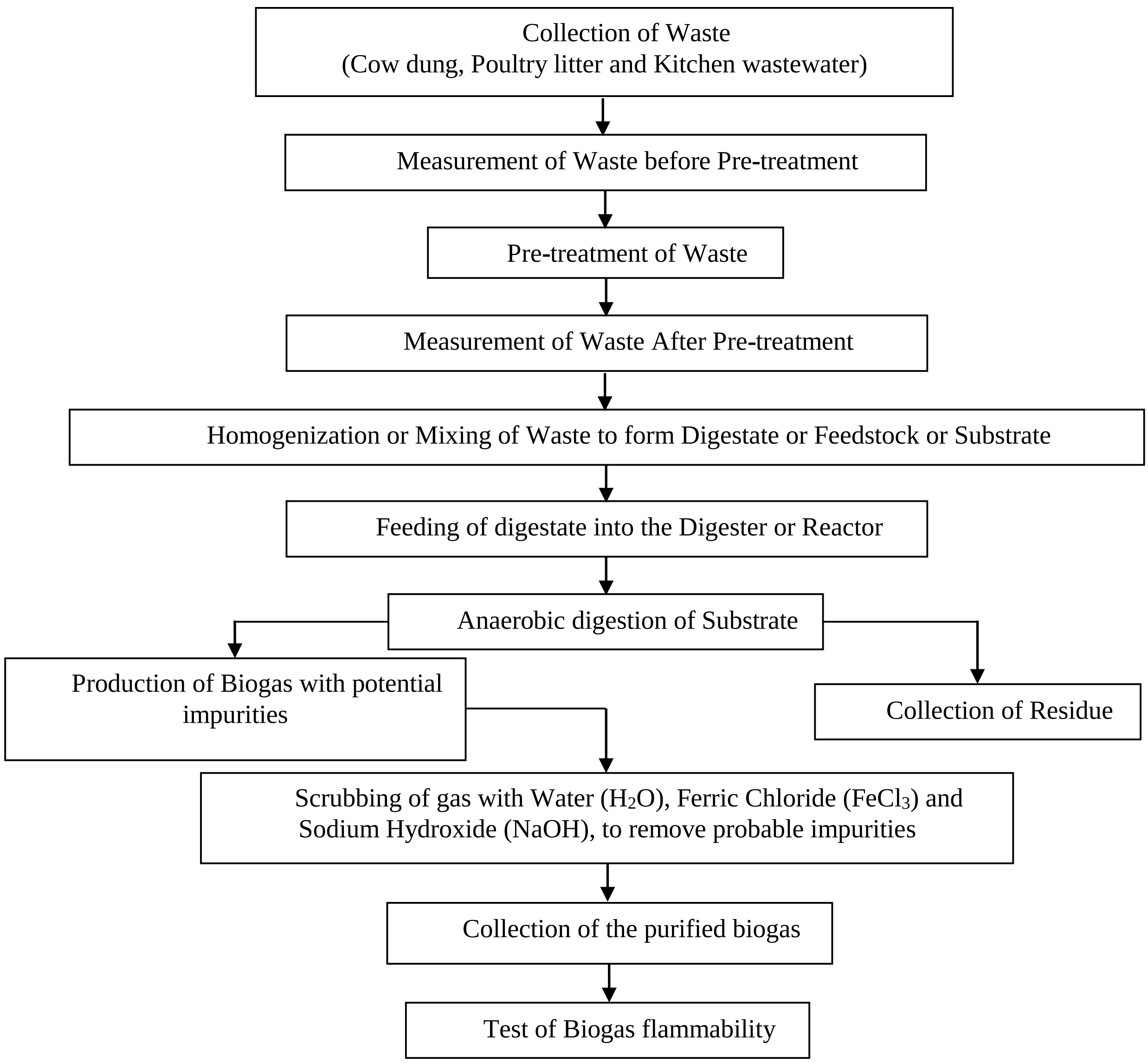

Figure 3.1: Biogas production flow chart

4. RESULTS AND DISCUSSION OF FINDINGS

4.1. The biogas production

The digestion process for the experiment was carried out under an ambient temperature range of 26 to 36°C, within a retention period of 20 days. The agitation of the culture inside the reactor was done every two days by shaking the reactor and this continue until the 6th

day, when the gas production commenced. The following readings were taken as shown in Table 6.1. The early gas yield shows that the nature of substrates used are non-lignocellulose, as they decompose faster due to high organic microbes.

Table 4.1: Gas yield from the experiment

S/no.	Days	Volume (ml)
1	6th	1000
2	8th	2000
3	10th	2000
4	12th	2000
5	14th	1000
6	16th	500
7	18th	0

The raw gas collected totaled 8500ml. A summary of the experimental procedures for the generation of the biogas using cow dung, poultry litter and kitchen wastewater as substrate are tabulated below (Table 6.2).

Table 4.2: Final result of the experiment carried out

Cow dung Before/after treatment		Poultry litter Before /After Treatment		Kitchen Waste Water	Total volume of waste	Mix Ratio	Oven Drying	Total period of digestion	Total Volume of Biogas produced
3.5kg	3.2kg	3.5kg	3.3kg	5kg	11.5kg	1:1:1.6	90°C	20 days	8500ml

4.2. Flammability test before scrubbing

The raw biogas was tested for flammability; the result was that the produced biogas did not flame. The reason is not far-fetched as it was earlier established in literature that impurities such as carbon dioxide, water vapour, and hydrogen sulphide, when present in biogas, affect the flammability of the gas (Rincón, Heaven, Banks & Zhang, 2012). To decontaminate the gas of these combustion-inhibiting impurities, chemical scrubbing processes were applied to obtain pure methane that is very combustible.

4.3. The scrubbers

Ferric Chloride ($FeCl_3$) and Sodium Hydroxide (NaOH) were solvents used for the scrubbing of the raw biogas. Two 50Cl plastic bottles water containers were provided for scrubbing. The first bottle contained a solution of ferric chloride and the second held sodium hydroxide solution. Each scrubber had openings at the top for inlet and outlet, where rubber pipes were fixed for passage to each container from the pressure hose connected to the digester.

4.4. Scrubbing process

Scrubbing is the process of removing impurities from biogas in other to obtain pure methane. Two different scrubbing procedures were undertaken, ferric chloride solution was first used to remove H_2S and the second procedure was the use of sodium hydroxide solution to remove CO_2. These procedures follow the inference of Shah, et al. (2016) that removal of impurities in biogas, raises the methane content of the biogas, and primary methods of scrubbing biogas include the water and chemical methods. A diagrammatic representation of this is revealed as figure 6.1 below.

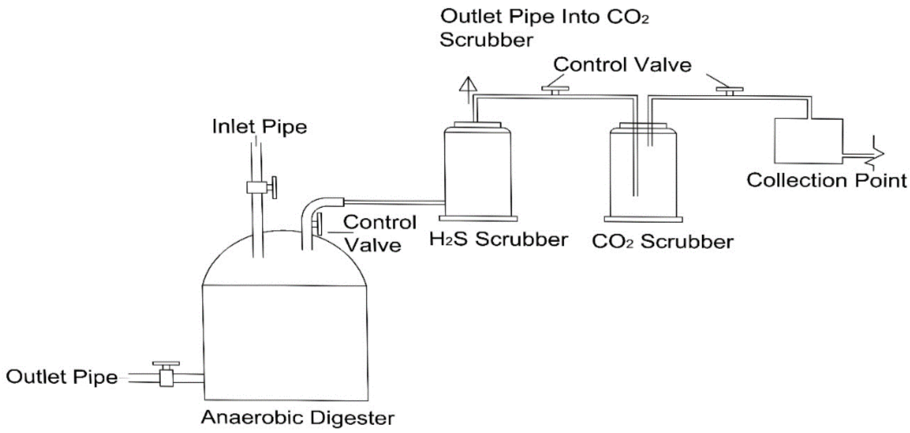

Figure 4.1: Schematic representation of the laboratory scale digester and it scrubbing system

The raw biogas was first passed through ferric chloride solution to remove H_2S through an upward delivery. This process produced heavy gas bubbles. The escape of the gas from the ferric chloride solution turned the solution dirty brown. The gas then entered the next chamber containing sodium hydroxide solution. The result of this also produced strong bubbles in the sodium hydroxide, turning it slightly milky.

4.5. Flammability test after scrubbing

The decontaminated biogas (after scrubbing with $FeCl_3$ and NaOH) was then retested for flammability and the result was a pressurized deep blue flame. The result confirmed that H_2S and or CO_2 must have been present in the earlier collected raw Biogas, which led to the failure of the flammability test. This highlights the need for biogas scrubbing after collection, to eliminate potential impurities.

5. Summary, Conclusion and Recommendations

In this section, summary of the study efforts and deductions, conclusion and recommendations are succinctly presented.

5.1. Summary

A total of 11.5kg of waste (cow dung, poultry litter and kitchen wastewater) after pretreatment, was fed into the developed digester as substrate. On the 6th day of digestion, biogas was produced and the gas production lasted for 18 days until no gas was further generated. Findings also indicated that 8500ml of raw biogas was obtained from the 11.5kg of substrate. The non-flammability of the raw biogas showed that it contained some impurities that had to be removed through a process called scrubbing. Two scrubbing agents - Ferric Chloride ($FeCl_3$) and Sodium Hydroxide (NaOH) solutions, where used to remove hydrogen sulphide and carbon dioxide respectively. The flammability test after scrubbing showed a positive result as the biogas flamed deep blue.

5.2. Conclusion

This study explored the potential of biogas production, using locally available waste (cow dung, poultry litter and kitchen wastewater), as an alternative source of energy. Results obtained in this work demonstrate that it is possible to achieve the production of biogas through an anaerobic digestion process. The findings also establish that on a pilot scale, 8,500ml of raw biogas can be produced from 11.5kg of combined waste. To use the generated biogas, a process known as scrubbing is required to decontaminate the gas and make it flammable. The gas produced which burns deep blue flame can be used for heating purposes in the University Cafeteria and in other units of the Universities where heating is required. Been a clean source of energy for heating purposes, the process is considered to be eco-friendly and sustainable.

5.3. Recommendations

Based on the findings of this study, it is recommended that a bigger anaerobic digester be developed to take larger substrate, so that landfilling of University wastes would be greatly reduced and possibly eliminated. Also, if on a pilot scale, 8,500ml of raw biogas was produced from 11.5kg of combined waste, then there is need to explore the large amount of organic waste that are readily available within our septic tanks or sewage systems in the University. Lastly, Professionals in the built environment of University of Uyo should advance research on sustainable waste management systems in buildings. This is majorly achievable if the University of Uyo would give grants solely for the purpose of exploring the potential of biogas production using all available wastes on campus.

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APPENDIX

Figure 9.1: Cow dung littered along the road of University of Uyo Annex Campus

Figure 9.2: The developed anaerobic digester

Figure 9.3: Wastes for the experiment: cow dung, poultry litter and waste water

Figure 9.4: Poultry litter