AN EVALUATION OF WASTE MANAGEMENT STRATEGIES TO SUSTAINABLE ENERGY (BIOGAS) GENERATION IN RESIDENTIAL BUILDING

(A Case Study of WUFPOLY Birnin Kebbi, Nigeria)

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Abstract

Biogas is a mixture of gases, primarily consisting of methane and carbon dioxide produced from agricultural waste, manure, municipal waste, plant, sewage, green waste and food waste. It is a renewable energy source. The research examines the use of 6kg of fresh cow dung from a cattle ranch, 12 litters of clean water, neatly washed use paint buckets with cover containing 35Liters, tire tube of size 180/65-15psi, 1 inch water valve (liquid discharge), 2 gas valves of 1 inch diameter, 3metal strap clip adapter of 1 inch diameter, 4 rubber nipples of 1inch, 0.5m flexible steel pipe, 3m poly-varec chloride (pvc) flexible polyester service gas pipe, 4minute gum, 60 inches length of hose pipe and tin polythene sheet. The study was carried out in an air tight of cow dungs and water solution for a period of thirty days (30 days). The results from the experiment demonstrated that 0.070307kg/cm² of raw biogas was obtained from 6kg of combined waste (cow dungs and water) can be used for cooking food using a gas burner for a period of 8 to 10 minutes. The concept was waste – to –energy, which addresses sustainability problems such as reduction of environmental pollution, recycling waste for energy generation (biogas) and transmutation into bio- fertilizer (liquid) through an anaerobic digestion process, the implementation of waste treatment plant in residential buildings will help to reduce green house gases (GHG), cost of cooking gas and farming fertilizer as farm input for healthy living just to mention but few.

Keywords: Waste Management, Sustainable Energy, Residential Biogas

Introduction

Energy is a driver of economic growth, obtained from various primary sources that are not limited to coal, petroleum, nuclear but also incorporates renewable sources from wind, solar and biomass. Of these, the most widely used source is the non-renewable fossil fuel which account for more than 80% of global primary energy consumption with its attendant environmental pollution (Duerr, Cruden & McDonald. 2018). Actualization of the United Nation's Millennium Development Goals. Nigeria is not left out from such immense dependence on fossil fuel. A country endowed with primary energy resource with a record of the world's tenth largest reserves of crude oil estimated to be about 36 billion barrels (about 4.896 billion tons) of oil in 2016, is yet to attain sustainable development with resultant effect on the environment. Statistical Review of World Energy-British Petroleum and Oil Reserve in Nigeria. The increasing concern for environmental health, eco-friendly waste management and sustainable energy production constitute the focus of many trade bodies, regulatory agencies, states and countries of the world. Energy efficiency and renewable energy are two key components of sustainable energy that provide significant environmental benefits. Promoting circular economy in the surroundings of an organic fraction of municipal solid waste through anaerobic digestion treatment plant for producing biproducts of gas and liquid production with large impact and economic factors (Abad, Avila, Vincent & Front, 2019).

Nigeria is a populated country in Africa with significant resources of organic waste. Rapid urbanization, industrialization and agricultural activities have created environmental concern such as environmental pollution from municipal, industrial and agro-allied waste. Waste, an output of any operational system, which has continued to grow with more attention to an effective waste disposal management system. No doubt, there has been infinitesimal

prospect into waste to energy technology (WTE) as a waste management strategy (Akhator, Obanor & Ugege. 2017). This approach embodies the concept of the four R's, such as reduce, re-use, recycle and renewable energy which has generally been accepted as a useful principle for waste handling. Kothari. (2014). Waste-to-energy technology has been a viable waste management strategy in establishing sustainable waste disposal, delivery renewable energy and providing better end products such as biogas generation and farm manure in comparison to other disposal methods (landfills or incineration). Hence biogas, a waste-to-energy strategy, do not only provide renewable energy in the form of heat, electricity, fuel and methane gas for cooking from low/ negative value organic waste (Kothari, *et al.*, 2008).

Sustainability in Waste-To-Energy Technology

The waste normally includes; solid, liquid and gaseous materials that accumulates with time. Waste management which generally involves the collection, transfer, treatment, recycling, resources recovery and disposal of waste in any location (Okey, Umana, Markson & Okey, 2013). The major problem caused by wastes to the environment is pollution characterized by various types of waste, which must be effectively managed through appropriate reduction, reuse and/or recycled practices in other to maintain a clean municipal environment (Dauda & Osita, 2009). The management of municipal waste emerged as one of the most serious problems facing environmental protection in developing countries in Africa and some parts of the world. In most of these countries including Nigeria, Municipal Waste Management involves just the collection and transfer of waste to land fill or dump site with little or no conversion practices (Okey, *et al*., 2013). The point in the transition at which WTE becomes relevant is in the resource recovery stage (Akhator *et al.,*2017). It is a versatile energy source that can significantly reduce the use of fossil fuels and consequently contribute to energy security, which is a global challenge (Abubakar & Ismail, 2012). The factors for consideration to include; feasibility, ease of use (social acceptance), education requirement, infrastructure needs, economics, a potential for pollution, GHG emissions, land use requirements and technology needs for further development. Waste to energy (WTE) technologies have the potential to reduce the volume of the original waste by 90%, depending on the composition, by recovering otherwise lost energy and metals in MSW, thus providing a means of alternate/renewable energy and a reduction of society's use of precarious energy resources can be realized (Voelker, 2004; Wang, 2009; Kathiravale, 2008; Kothari, *et al*., 2013). No doubt, the lack of necessary and adequate WTE technology in developing countries like Nigeria is still a dominant issue. There are no operating engineered landfills, bioreactors or large-scale ADs for the production of biogas. Therefore, resources that could potentially be harnessed and recovered for WTE are untapped through indiscriminate disposal in dump sites, which consequently impacts negatively on the environment (Duerr *et al*., 2018).

Energy Potential of Waste and Some Selected Biomass

Biomass is an industry term for getting energy by burning wood and other organic matter. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Biofuels are the solid, liquid and gaseous fuels, which are mainly produced from biomass. It is synonymous to bioenergy, a renewable energy made from available materials derived from biological sources. According to Urban and Mitchell (2014). Nigeria has vast biomass resources that are left untapped at the moment. Gasification produces a synthesis gas with usable energy content by heating the biomass with less oxygen than needed for complete combustion. Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen. Pyrolysis is also the main process to produce synthetic diesel from plastics (2011) survey. Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen. Corn Stover and wheat straw residues are baled for combustion or converted into a gas using an anaerobic digester. Waste sludge as a valuable resource of renewable energyrecovery is treated in several ways to recover different value added products, viz; energy rich gas (methane, hydrogen syngas), Liquid biofuels (bio-diesel, diesel oils), construction material (bricks, cement , pumice, slag, artificial light weight aggregates), bioplastics, protein and hydrolytic enzymes, bio fertilizer, bio-sorbent, bio-pesticides, electricity generation using microbial fuel cells, nutrient (nitrogen and phosphorus) and heavy metals. (Tygal and Lo, 2013). The biomass resources of Nigeria have been estimated to have a capacity of about 8 - 102 Mega joule of energy (Ikuponisi, 2014). The effort towards utilizing this potential for energy production is still not sustainable at the moment. The volume of wastes generated in Nigeria on daily basis is on the increase. The waste density of municipal solid waste in Nigeria ranged from 280 to 370 kg/m^3 with the waste

generation rates in the range 0.44 to 0.66 kg/capita/day. (Ogwueleka, 2009). Ngumah *et al*., (2013) noted that Nigeria generates about 542.5 million tons of organic waste which has the potential of yieldingabout 25.53 billion m³ of biogas (about 169, 541.66 MWh) and 88.19 million tons of bio fertilizer.

Animal waste

Animal manure is a valuable source of nutrients and renewable energy. However, most of the manure is collected in lagoons or left to decompose in the open which pose a significant environmental hazard. 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 a potential negative impact on the environment, if not managed optimally. To prevent emissions of greenhouse gases (GHG) and leaching of nutrients and organic matter to the natural environment it is necessary to close the loops from production to utilization by optimal recycling measures. The introduction of tighter environmental controls on odour and water pollution means that some form of waste management is necessary, which provides further incentives for biomass-to-energy conversion (Zafar, 2013). The animal production sector is responsible for 18% of the overall greenhouse gas emissions, measured in carbon (IV) oxide equivalent and for 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 originates from the worldwide animal production sector (Steinfeld *et al*., 2006). Animals waste includes livestock manures from cow dungs, sheep, pig, goat, poultry manure and other domesticated animals. Abubakar and Ismail (2012), investigated the effectiveness of cow dung for biogas production. The averaged cumulative biogas yield and methane content observed was 0.15 L/kg Volatile solid (VS) added and 47%, respectively. In the same vein, Alvarez and Liden (2009), established that the biogas production in anaerobic digestion in farm-scale units is typically performed under mesophilic conditions when used for producing domestic fuel and stabilizing animal waste for the use of digested manure as a fertilizer. The results suggest that in a system digesting a mixture of llama-cow-sheep manure at low temperature (291–298) K equivalent to (17.85–24.85) °C. The methane yields obtained in the mixture experiments were in the range 0.07–0.14 m³ /kg added, with a methane concentration in the gas of between 47% and 55%. Castrillon *et al.,* (2013), studied biogas production from cattle manure by adding food waste and crude glycerine from the biodiesel industry as co-substrates. It was observed that methane content in biogas was up to 78%. In research conducted by Recebli *et al.,* (2015), Biogas production potential from bovine animal and poultry manure was separately studied. Firstly, 350 kg bovine animal manure blend (175kg manure +175kg water) filled to the tank and the process occurred. Secondly, 375 kg poultry manure blend (50 kg manure+325 kg water) was filled to the tank and the processes done. Then the biogas production rates were evaluated and compared for two processes. Results showed that daily 6.33 m³ and 0.83 m³ biogas productions were obtained from fermented mixture of animal waste and water (Ogwueleka, 2009). Ngumah *et., al* (2013) noted that Nigeria generates about 542.5 million tons of organic waste which has the potential of yielding about 25.53 billion m³ of biogas (about 169 541.66 MWh) and 88.19 million tons of bio fertilizer.

Municipal Solid Waste (MSW)

Municipal solid waste (MSW) comprises of combined domestic, commercial and industrial waste generated in a given municipality or locality (Fobil, 2005 Kothari, et al., 2010). The organic fraction of municipal solid waste (OFMSW) is a term often used in Ireland and the UK to describe food and garden waste in household and commercial waste streams. In many EU countries OFMSW is simply referred to as bio waste (Browne *et.,al* 2014). Municipal solid waste could be in any of this form, such as organic/ food, paper/ polythene, cardboard, textiles, plastic, Glass and metal, garbage and others such as dust, ash, ceramics. The biomass resource in MSW comprises the putrescible, paper and plastic and averages 80% of the total MSW collected (Zafar, 2015).

Sewage Waste

Sewage waste is human excreta that are very similar to the other animal wastes. Energy can be extracted from sewage using anaerobic digestion to produce biogas. The sewage sludge that remains can be incinerated or undergo pyrolysis to produce more biogas.

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. Generation of nutrient rich digestate, which can be used as fertilizer, the process can naturally occur in anaerobic environments like river sediments, deep soil or waste landfills. The AD process can also be engineered to take place in a dedicated facility known as an anaerobic digester; primarily a closed vessel kept with a culture of microorganisms, fed regularly with digestible (organic) matter (Botheju and Bakke, 2011). The gaseous mixture, called biogas, can contain 50 to 95 percent methane depending on the source. Anaerobic digestion occurs naturally inside landfills due to the presence of large amounts of organic waste and the scarcity of oxygen. This emits a biogas normally composed of about 50% methane, 50% carbon (IV) oxide, and trace amounts of other gases (EESI, 2009). The first documented engineered anaerobic digester was put into operation in Mumbai, India in 1859 (Monnet, 2003), using the process for waste treatment and utilizing biogas for lighting. Anaerobic digestion has now become a well-established technology used for handling multitudes of waste categories including those of domestic/municipal, agricultural and industrial origins. (Ngumah *et al*.,2013, Voelker, 2004, Matevz, & Matjaž, 2011). Compared to alternative treatment methods, the merits of AD include low sludge production, high organic loading rates, energy value of methane and low energy consumption. In the light of current global consciousness of environmental sustainability, AD is regarded as a promising process, both as a renewable energy generation scheme and a waste stabilization method. Anaerobic digesters further contribute to reduce greenhouse gas emissions (Nielsen *et al*., 2009, Liu. *et al*., 2008).

Operating Temperature

In anaerobic digestion process, temperature is not only important for microbial metabolic activities but also for the overall digestion rate, specifically the rates of hydrolysis and methane formation. Digesters are designed to run at different target temperature ranges. The temperature ranges are typically 86 - 100° F for mesophilic (30 – 42°C) and 122 - 140° F for thermophilic (43 – 55°C) There are different populations of anaerobic microbes that thrive in these temperature zones. In practice, most of the digesters are designed to operate at mesophilic range, between 30 to 38°C. Thermophilic digesters require less time to process feedstock but may have higher costs and be more difficult to operate. In general, mesophilic digesters are easier to operate and maintain. Less at risk from ammonia nitrogen toxicity and requires less process heat (Alvarez & Liden, 2009).

Mesophilic Digestion

The anaerobic digester that operates at the mesophilic temperature range (30-38°C) is known as mesophilic digestion. Mesophilic anaerobic digestion is most common system which has a more stable operation but a lower biogas production rate. Another disadvantage of mesophilic digestion is that it does not reduce the pathogen concentrations enough to produce Class A bio solids, a bio solid that contains no detectible levels of pathogens (WEF, 2004).

Thermophilic Digestion

The anaerobic digester that operates at the higher thermophilic temperature range (50 to 65°C) is known as thermophilic digestion. Interest in the thermophilic digestion developed based on the facts that higher temperatures reduce pathogens and thermophilic temperatures provide more rapid reaction rates than mesophilic temperature. Class A quality bio solids can be produced from thermophilic digestion when the time temperature criteria specified in the US EPA Part 503 are satisfied. Thermophilic anaerobic digestion in general are more efficient in biogas production but associated with higher maintenance cost (Abubakar & Ismail, 2012).

Anaerobic Digestion System

Anaerobic digesters are typically large or small reactors constructed of concrete, rubber or steel. The volume of the reactor depends on the volume of waste to be processed in the system. With most conventional digesters, a retention time of 20 - 30 days is required to convert manure solid into methane. In a simple digester, using steel, plastic or concrete, the key configurations are the tank/ chamber with the inlet for waste input, outlet for digestate removal as fertilizers, a gas valve outlet for gas collection and further processing (Sharvelle & Loetscher, 2011).

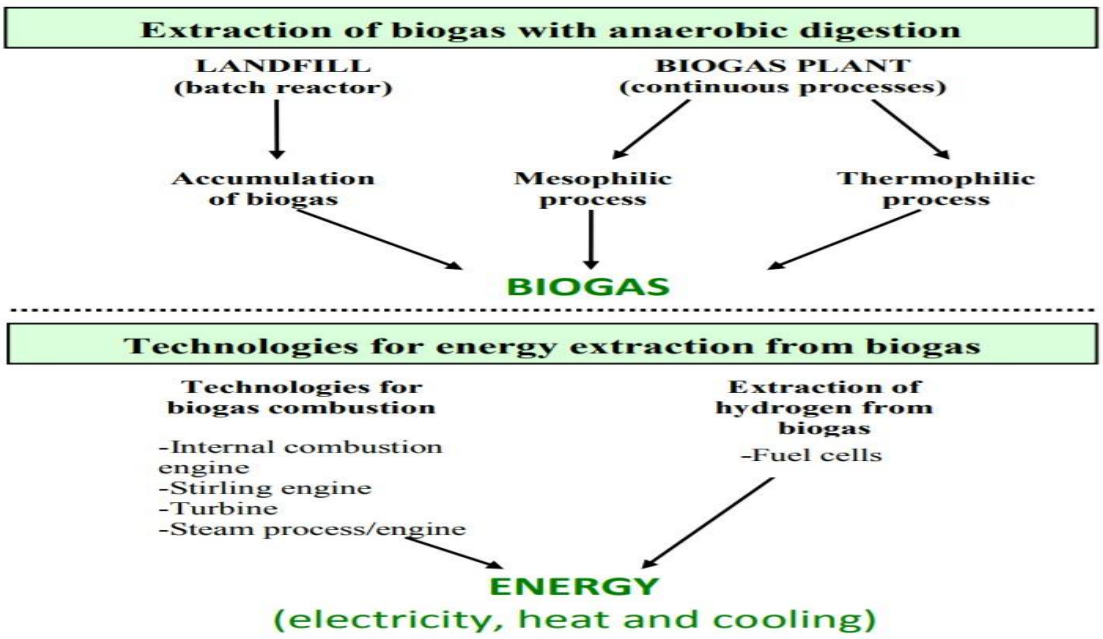


Fig 1: Anaerobic Digestion System.

Anaerobic Digestion of Animal Waste

Anaerobic digestion is a unique treatment solution for animal manure. **Co-digestion** of animal manure with various biomass substrates increases the biogas yield and offers a number of advantages for the management of manure and organic wastes (Nielsen *et al*., 2008) and for mitigation of greenhouse gas (GHG) emissions. In co-digestion of plant material and manures, 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). The main factors that influence biogas production from livestock manure are pH and temperature of the feedstock. It is well established that a biogas plant works optimally at neutral pH level and mesophilic temperature of around 35^{o} C. Carbon-nitrogen ratio of the feed material is also an important factor and should be in the range of 20:1 to 30:1. 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. The gas production per digester volume can be increased by operating the digesters at a higher solids concentration. Batch high solids reactors, characterized by lower investment costs than those of continuously fed processes, but with comparable operational costs, are currently applied in the agricultural sector to a limited extent (Zafar, 2018). Hydraulic retention time (HRT) is the most important factor in determining the volume of the digester which in turn determines the cost of the plant; the larger the retention period, higher the construction cost.

Biogas

Biogas is gaseous fuel that is naturally produced from the decomposition of organic waste. When organic matter, such as food scraps and animal waste, breakdown in an anaerobic environment (an environment with the absence of oxygen) they release a blend of gases, primarily methane and carbon dioxide. It typically contains between 60-70% methane. Other constituents include carbon dioxide, hydrogen sulphide, ammonia, and other trace organics. Biogas contain significant amount of hydrogen sulphide (H_2S) gas which needs to be stripped off due to its highly corrosive nature. The removal of H_2S takes place in a biological desulphurization unit in which a limited quantity of air is added to biogas in the presence of specialized aerobic bacteria which oxidizes H_2S into elemental Sulphur. Biogas is combustible, and therefore produces a deep flame, and can be used as an energy source such as domestic cooking, industrial heating, combined heat and power (CHP) generation as well as a vehicle fuel (Birkmose, 2007).

METHODOLOGY

Materials

The materials used in this research includes 6kg of fresh cow dung from a cattle ranch within the Waziri Umaru Federal Polytechnic Staff Quarters in Birnin Kebbi, Kebbi State. 12 litters of clean water, clean used paint rubber bucket with cover constructed to contain 35Liters, tire tube of size 12 psi, at the collection point, 1 inch water valve, 2 gas valves of 1 inch diameter, metal adapter of 1 inch diameter, 4 rubber nipples of 1inch, 1inch flexible steel pipe, 4-minute gum (adhesive), 3m of 1 inches length of hosing pipe and polythene sheet. The table below itemized the materials used in this experiment.

Table 1: Materials used in the Experiment

S/N	DESCRIPTION	QUANTITY
1	Cow dung	6kg
2	Water	12Lt
3	Plastic bucket	35Lt
4	Tire tube size 12psi	1
5	Flexible pipe	1
6	Gas valve	2
7	Hosing pipe (1inch)	3 meters
8	Pressure gauge	1
9	Metal Adapter	1
10	PVC nipple	4
11	Water Valve	1
12	4-minute glue	2
13	Gas Regulator	1

Selection of Digester

In this research the type of digester that has been constructed was the Floating Drum digester. The digester was made with a plastic rubber paint containing a minimum of 35 liters, the digester selection is depending on the amount of waste to be used in the digester, and the size of the digester and the amount of cow dung to be used determine the amount of gas to be generated from the digester to the collection point.

Drilling of Holes

Two holes were drilled, each of these holes were drilled at 25mm diameter, plumbing fittings used in this experiment were all considered to be in the same dimensions as it will make the components to be well sealed and prototype, 25mm hole was drilled at the top of the digester for gas outlet, the gas outlet is the hole where the gas will pass through and it will be trapped in the reactor and the reactor is the gas collection or storage point, the other hole at the bottom was drilled to discharge the waste in the digester after using it for anytime long which serve as a manure.

Assembling the Fittings

This step is to assemble all the fittings in this construction, the 25mm diameter Male Adapter was fixed inside the digester to attach the 25mm diameter /500mm long Flexible Steel Pipe, two 25mm diameter Pvc Nipple were fixed in the pipe which will attach the Gas Valve to connect with the Pvc Equal Tee, the Pvc Equal Tee was connected with a

Pvc Nipple in the three sides, providing two channels of flow, this ensure that the gas generated will flow in two channels which is the Inlet and the Outlet. The use of 4minutes Glue was used to ensure all the connections were fully sealed, after sealing the connections Air was blown into the collection point to test if any leakage will occur by using ordinary water to the connections, if air leakage occurs make use of the glue to make it prototype.

Inlet Flow

The inlet flow transfers the Gas generated from the Digester to the collection point, size 12 Rubber Tuber was used by removing the valve of the Tube to allow free flow of gas in to the Tube, 1.5 meters long of a gas Hosing pipe was connected in the both sides of the Equal Tee, where the Gas Valve from Flexible Pipe will be opened and the other Gas Valve will be closed so that the gas generated will flow in only one direction which is the Inlet.

Outlet Flow

The outlet flow pipe takes the gas generated from the digester to the collection point by closing the inlet gas valve and opening the outlet gas valve, gas regulator was used to test the flammability of the gas generated.

Biogas produced

The result indicates that anaerobic digestion has become an alternative source of energy by the use of cow dung. The volume of biogas produced from the digester to the reactor was measured using Pressure Gauge with a result of 1 Psi (Pound-force per Square Inch) related to vacuum and was converted to Kg/cm² (Kilogram per centimeter square) having a total of 0.070307kg/cm².

Flammability test

The raw biogas was tested for flammability, the produced biogas was burning with clear blue flame and the combustibility was measured using a stopwatch. The total gas yield 0.070307kg/cm² was burnt and recorded at 216.3 seconds which approximately 3.6 minutes. A digester has been designed to contain 35 litters of slurry that is the mixture of 6k cow dung and 12 litters of water which has been digested for 30 days, this experiment was carried out under Mesophilic temperature. The anaerobic digestion continued for 21 days where the gas yield decreases and the mixture was discharged to the plants as manure.

Summary

The result shows that in this experiment, a total quantity of 6 kg of waste (cow dungs) as described in the experimental procedures was mixed with 12Lt of water and fed the digester. After 30 days of retention period, anaerobic digestion occurs. Gas production commences and lasted for extra 20 days and still produces the biogas, the findings also indicated that from the experiment 0.070307kg/cm² of raw biogas was produced from 6kg of cow dung and 12Lt of water after 20 days.

CONCLUSION

The experiment carried out in this course of study was to explore biogas production using locally available cow dung for an alternative source of energy to be used in this institution and beyond. Results obtained in this work demonstrate that it is possible to achieve the production of biogas through anaerobic digestion, the cow dung could be used as a suitable substrate for biogas production. Biogas production, if carried out in institution, would not only provide an alternative source of energy but would be a means of waste recycling in Nigeria.

RECOMMENDATIONS

- Residential building in Nigeria, like the polytechnic should adopt such technic of recycling the organic waste to methene gas (biogas) for cooking, hygienic environment and cost efficiency within the built environment.

- Design, fabrication of biogas system and storage facilities are necessary to facilitate development and propagation of efficient use of biogas readily available taken into cognizance the health and safety of human and the immediate environment.

- Waziri Umaru Federal Polytechnic Birnin Kebbi can augment its biogas production using cow dung if ranch can be constructed in a sustainable area where these animals are kept and preserved to avoid been littering the school environment for the purpose of grazing.

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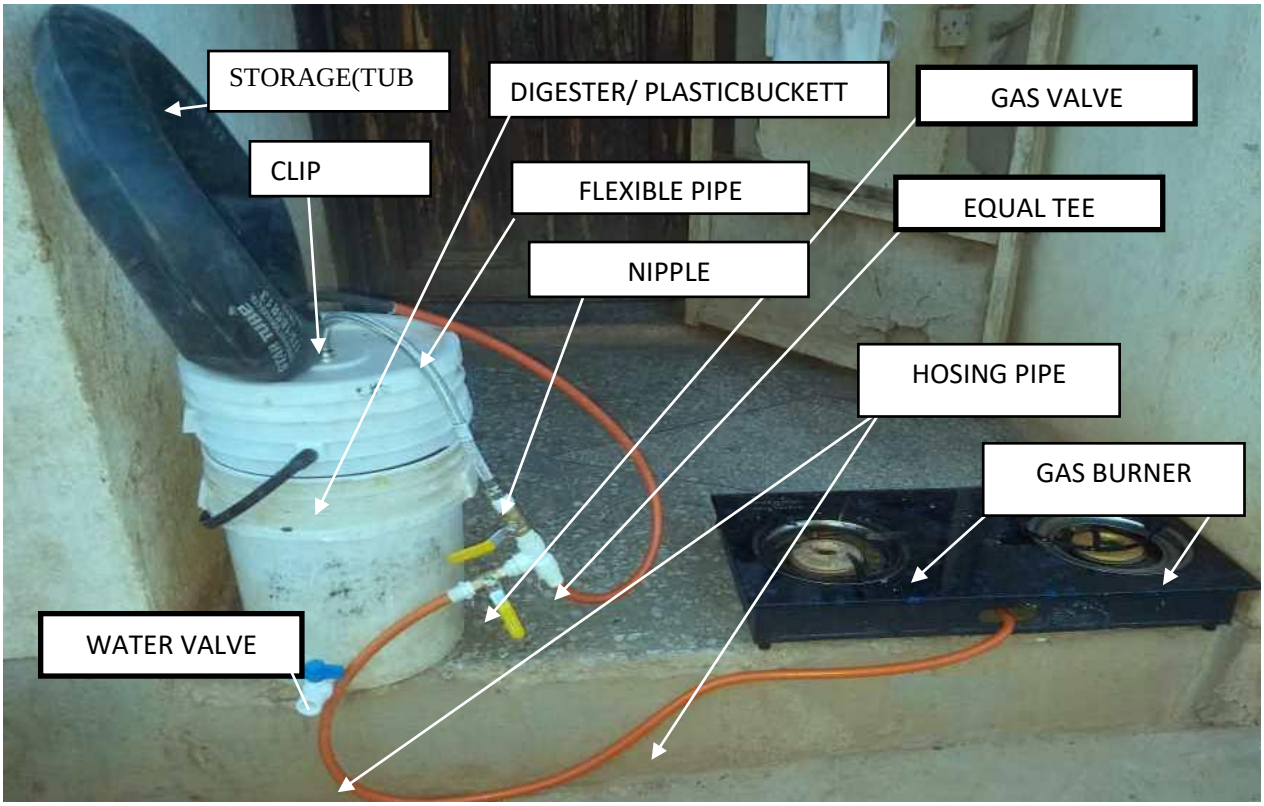
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Appendix I



Labeling of Digester Constructed

Appendix II



Gas Valve



Gas Regulator



Male Adapter



Equal Tee



Hose Pipe



Water Valve



Clip



Flexible Pipe



Pvc Nipple



Tube



Plastic Bucket



4Minutes Glue



Cow Dung