

Anaerobic Digestion of Agricultural Wastes: A Potential Remedy for Energy Shortfalls in Nigeria

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Citation: Usman MN, Suleiman MA, Binni Mi (2021) Anaerobic Digestion of Agricultural Wastes: A Potential Remedy for Energy Shortfalls in Nigeria. J Waste Manag Disposal 4: 104

Abstract

We live in a world where wastes are generated on a daily basis, while some of the wastes are generated on a seasonal basis, such as agricultural wastes. Agricultural wastes are produced seasonally in large quantities and readily available after every post-harvest operation. These wastes have the potential to be converted to useful products which can aid life and increase economy by creating jobs, particularly in Nigeria, but sometimes they are left unused and litter the environment, afterward, causing environmental degradation. These wastes can produce power through anaerobic digestion by the metabolic splitting of matter which is organic in nature into chemical components in the absence of oxygen. The dry anaerobic digestion process is an innovative waste-recycling method to treat high-solid- content bio-wastes. The wastes are passed through hydrolysis, fermentation, acetogenesis and methanogenesis metabolic reactions thereby decomposing them to usable state where they can be used in biogas production. Nigeria has the potential of generating daily 6.8 million m³ of biogas through animal waste, which will be profitable in eliminating or reduction of waste menace and nuisance of both local and urban waste. Furthermore, the production of biogas from agricultural wastes and biomass in Nigeria would be suitable for various fuel requirements in the household, industrial and agricultural sectors such as in cooking, lighting, water heating, running refrigerators, water pumps at home and in the farms; and electric generators domestically. Industrially, it could be utilized in drying rooms, running of internal combustion engines for shaft power needs and in small-scale industrial operations for direct heating applications such as in scalding tanks.

Keywords: Anaerobic Digestion; Agricultural Wastes; Biomass; Biogas; Energy

Introduction

Agricultural wastes mean the remains gotten from the cultivation and refining of unprocessed agricultural goods which are mostly poultry and poultry byproducts, crops remains, fruits, vegetables, dairy products, etc. These wastes are products of cultivation and processing of agricultural products which are mostly in the form of liquids, slurries or solids. Agricultural wastes which have another name of agro-waste consists of animal wastes i.e. manure and animal carcasses, refined food waste, waste from crops which include corn stalks, sugarcane bagasse, drops and culls from fruits and vegetable. Agricultural wastes could include dangerous and poisonous agriculture waste such as pesticides, herbicides, fungicides, insecticides, etc. [16]. According to Ioannou, *et al.* (2015), agricultural wastes is defined as the residues obtained from grown and processed raw farm products among which are crops remains, meat, fruits, roots, husks, residual stalks, vegetables, etc [9]. The products could be classified into natural and non-natural wastes which are obtained from farming activities like horticulture, livestock breeding, grazing land, forests, harvest remains.

Wastes or residues obtained from agricultural activities assume a large proportion of food production which is approximately 30% [9]. The wastes obtained from agricultural products could amount to 80% of the consolidated farm waste produced of which 5.27kg will be gotten per 1000kg per day [16]. These wastes are left unutilized i.e. to rot by themselves or sometimes destroyed by fire in open environment, which tends to pollute the environment. Some of these agricultural wastes contains useful nutrients such nitrogen, phosphorus, potassium, etc. which can be utilized on the farm as manure or can be used to produce power [18].

Agricultural wastes are usually not sparsely distributed to a particular place or location, but widely distributed in large quantity around the farm and the environment. This art tends to become a problem to the society, water bodies either surface or ground source, soils, crops, human settlement and animals around. These wastes affect the environment through direct and indirect contacts [12]. According to Obi, *et al.* (2016) agricultural wastes produced are as a result of the farming activity that is undertaken per time by the farmer [16]. These activities are as follows: Wastes obtained through farming activities- In the tropics, the soil supports farming activities thereby yielding good harvest, but this is not without the growth of weeds and insect which act as catalyst for growth of farm products. Pesticides and insecticides will be used to destroy these weeds and insects; this tends to excessive usage which results in distortion of the ecosystem and affecting other animals through food poisoning and contamination of the land. Some of these pesticides seep into water bodies through osmosis to affect the environment. At some points excessive application of fertilizer, so as to improve production, reverses to become a problem as some portion enters streams, ponds, rivers etc. through surface runoff or through irrigation methods chosen, thereby polluting the water bodies, the ground and even the air. Wastes produced through livestock- solid manure, organic materials, liquid waste such as urine, wastewater from sanitation and animal bath are some of the wastes gotten through livestock farming. These waste cause pollution of land, air and water to the residence which the livestock are reared and also emit odor, smell and greenhouse gases. The faeces of the animals' litter the land even though sometimes act as manure but when in excess become dangerous to livelihood and some organism to dwell comfortable. Some of these pollutants cause germs and diseases often times to human and the environment. Wastes from aquaculture- the increased need for feeding in aquaculture is the major source of waste in the system. The excess feed or unused feed by the aquatic life lead to the production of waste which either floods on the surface of the water or dissolve into it (water). The more the feed consumed by the aquatic life the more wastes is produced by them. These wastes can be managed by good water flow pattern; this is done by minimizing the fragmentation of the faeces and allowing the quick settlement and concentration of the solid waste.

Wastes management systems, disposal and reusability are attainable through the knowledge of the various characteristics of the agricultural waste. The various agricultural waste are characterized by their different quantities and qualities i.e. waste produced from food are of low strength having high liquid volume whereas those from livestock are of high strength with low liquid volume [11].

The knowledge of the characteristics of waste guarantees the pattern of treatment and/or the disposal method(s) to use and that will be effective. This knowledge is relevant because both liquid and solid waste have different treatment and organic matter contents. Table 1 shows different treatment and disposal methods of waste of different characteristics.

Wastes	Treatment and disposal methods
Liquid	
Dissolved organic wastes	Biological treatment, land disposal
Dissolved inorganic matter	Land disposal, physical or chemical treatment
Suspended organic wastes	Sedimentation, biological treatment, chemical precipitation, land disposal
Suspended inorganic matter	Sedimentation, land disposal, chemical treatment
Solid	
Organic wastes	Incineration, composting, land disposal, dehydration, soil conditioner, animal feed
Inorganic wastes	Land disposal

Source: Loehr, 1974

Table 1: Different Treatment and Disposal Methods of Waste having Different Characteristics

Agricultural Waste Technologies Usage Route

Waste from agriculture has some certain operations that they can undergo. These operations are carried for two purposes; either their residues are used rapidly, or stored under good conditions to avoid spoilage. The residues can be made unsuitable for processing to the desired end product. Some of the applications that agricultural waste can be put through are as follows:

Pyrolysis

In pyrolysis, there is a thermo-chemical breakdown of organic waste in the absence of oxygen in a high temperature inside a secluded environment which produces solid, liquid or gaseous products. This process reduces the volume of agricultural waste by 50-90% of the original size. Such process is carried out in temperature range of 450-500°C free of oxygen which produces pyrolysis gas, coke, char (fixed carbon + ashes) and coal tar (condensable gas) [23].

Pyrolysis is the most potent liquefaction process as it can produce around 80% of dry biomass as bio-oil. This process can be split into four groups: char recovery, liquid collection, biomass pre-treatment and pyrolysis.

Animal Feed

One of the logical ways of utilizing agricultural waste is the production of animal feed. Animal feed production from agricultural waste is one of the most beneficial returns on waste because the demand of animal feed is constantly increasing [2].

The technology used for the production of animal feed is sustainable to find an effective income for the agro-waste farmer and it can be handled in small-scale industries. The non-conventional and agro-byproducts can be divided into three categories such as energy-rich feeds, protein supplements and byproducts from cereal milling and palm-oil refining. This is presented in the Table 2

Feed source	Characteristics	Animals
1. Energy and protein concentrates (e.g. poultry litter, coconut cake, rice bran, soyabean meal)	High protein and high energy	Cattle, ducks, pigs, poultry
2. Good-quality crop residues (animal waste, cereal-grain waste, cassava peels etc)	High energy and high protein	Cattle, pigs, ducks
3. Medium-quality crop residues	Medium proteins	Ruminants, pigs
4. Low-quality crop residues	Low protein and high fiber	Ruminants

Source: Ajila et al., 2012

Table 2: Exploitation of nonconventional and agro-industry food resources as animal feed

Adsorption of Heavy Metals by Agricultural Waste

Heavy metals pollution has become a very serious issue of concern worldwide due to the danger it poses to both human and animal lives. Metals such as Zn (II), Cu(II), Cd(II), Mn (II) and Hg (II) are the heavy metal released into water through sources such as metal smelters, effluents from plastics, textiles, microelectronics and usage of fertilizers. These heavy metals need to be removed because they cause water degradation which is harmful to health [7].

In removing these heavy metals, low cost agricultural waste adsorbent materials can be used to eliminate and reclaim heavy metal ions from contaminated water body. This technology is advantageous because it reduces the concentration of heavy metals to a minimum level and it uses cheap bio-sorbent waste materials. The inexpensive agricultural waste materials used for reclaiming heavy metals are sugar beet pulp, coconut husk, sea weeds, bagasse, rice hull, sago waste, leaf mould, peanut hull, plants biomass, algae, moss peat, hazelnut etc [17].

The amount of heavy metal being adsorb can be calculated using equation 1.

$$q = \frac{V(C_0 - C_r)}{m} \quad - \quad - \quad - \quad 1$$

Where; q= quantity of absorbed heavy metal

V= volume of solution

C₀ and C_r = initial and final concentrations of metal

m = mass of adsorbent

Fertilizer Production Using Agricultural Waste

Agricultural waste disposal is becoming a huge task because of the increasing population and the inability to process these waste and dispose them appropriately. But these wastes can be collected and converted into organic fertilizer by the hydrolytic degradation using acids/alkali to obtain ethanol and other chemicals [20]. The hydrolytic degradation can be accelerated by heat.

These wastes (animal waste, dead plants, and other wastes) are fed into a decomposing tank for 20-25 days which produces methane (CH₄). The waste are removed from the decomposing tank and sun dried for 10-12 days. After drying, these wastes are used as bio-fertilizer. This fertilizer is eco-friendly and is cheap with less effect on the environment as compared to the inorganic fertilizer [22].

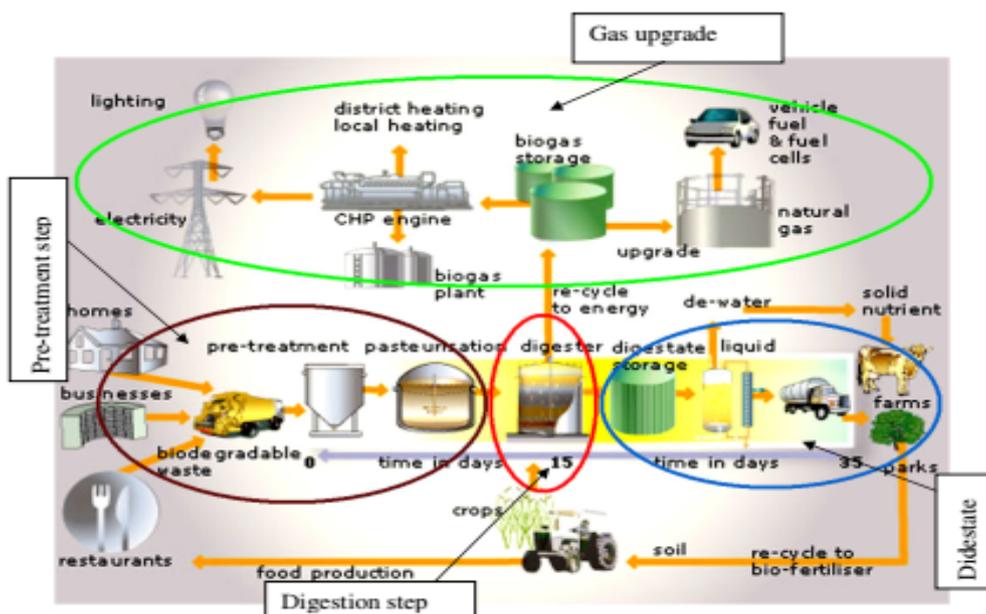
Direct Combustion of Agricultural Waste

Agricultural wastes are renewable biomasses which are relatively used in energy production. These wastes are used to produce power through combustion [15].

Combustion is the oldest and most basic form of agricultural waste disposal. It occurs by the reaction of the waste with oxygen to release heat. The heat released can be used directly or indirectly to produce power or electricity.

The electricity production is through two-step process; after the biomass is burned, it generates steam then the steam is used to drive the turbine which generates the electricity [4].

Some of the suitable combustion biomass waste includes residues from agro-industries, post-harvest wastes, food and paper production waste, wood wastes, sewage sludge and biogas from the digestion of organic and agricultural waste, municipal solid waste [8]. The moisture content of the agricultural waste is an important factor which determines its suitability for combustion, so it is better combustible when it is dried. Figure1 shows diagram of flow production for electricity from biomass through combustion.

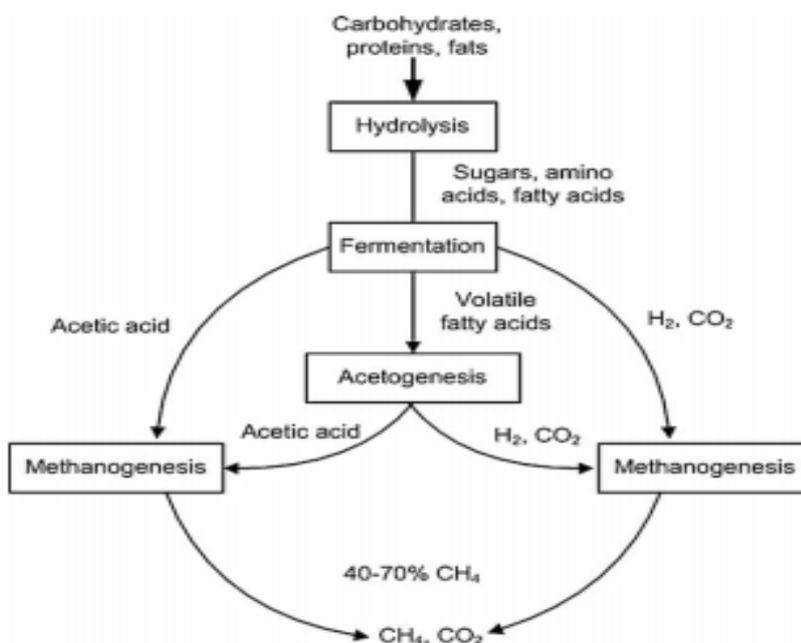


Source: REA, 2010

Figure 1: Diagram of general process of AD in electricity production through biomass by combustion

Anaerobic Digestion of Agricultural Waste as a Source of Power

Anaerobic digestion consists of the metabolic splitting of matter which is organic into chemical components in the absence of oxygen [13]. It is important in conversion of generated waste such as sewage sludge, organic farm wastes, and municipal solid wastes, and green/botanical wastes, organic industrial and commercial wastes. According to Khalid *et al.* (2011), anaerobic digestion is a process which converts or transforms almost any organic waste biologically into another form without involving oxygen [10]. This reaction degrades microbial population in the organic waste into useful product of biogas and other energy-rich organic compounds as the by-product [10]. Figure 2 shows the anaerobic decomposition which involves a series of metabolic reactions such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis.



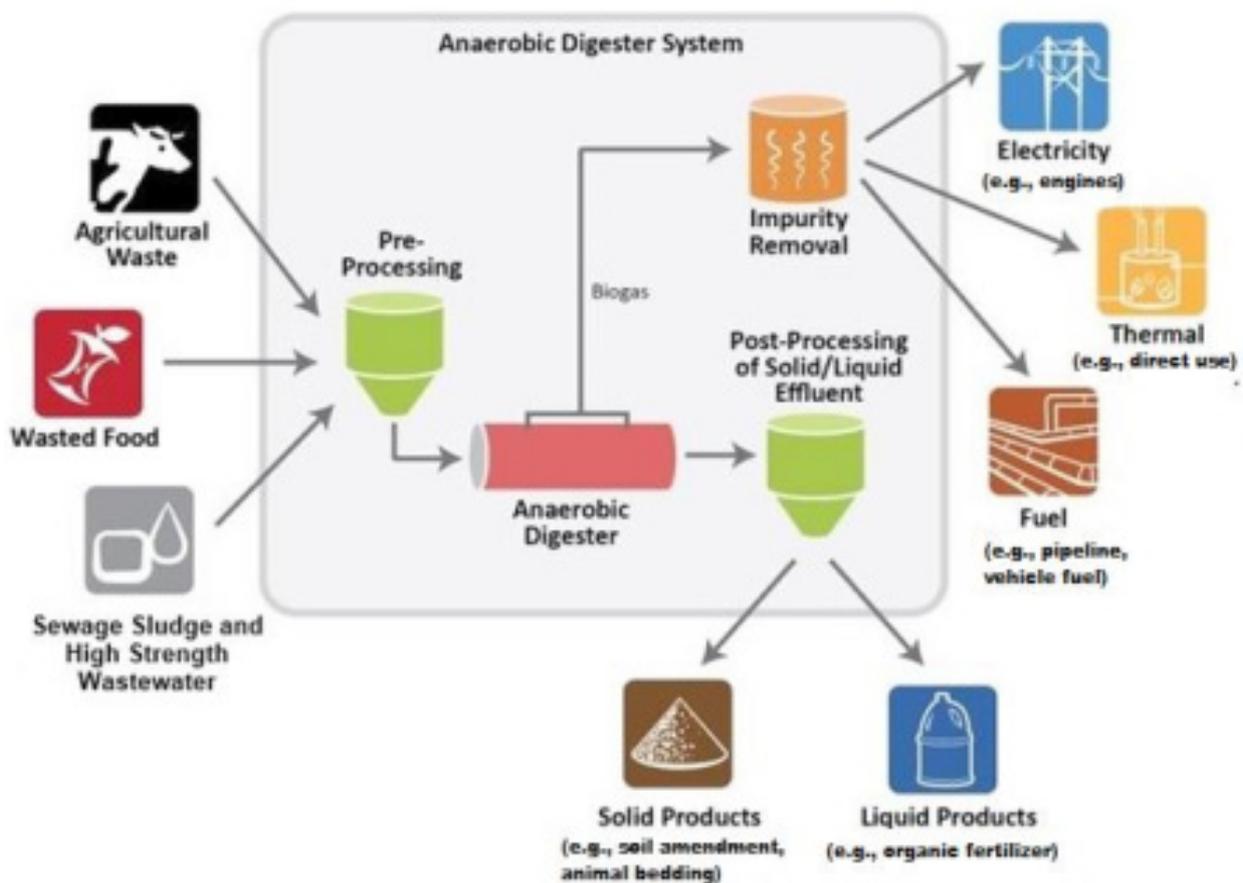
Source: Li *et al.*, 2011

Figure 2: Metabolic reactions for anaerobic digestion

Anaerobic digestion is usually performed on several waste products such as plant residues, industrial and agricultural waste, and municipal wastes. Additionally, anaerobic digestion possess benefits over aerobic process due to a low energy requirement for operation and low biomass production, and this is considered a viable technology in the competent treatment of organic waste and the simultaneous production of a renewable energy [10]. Different groups of microbial organisms are involved in the degradation process of anaerobic digestion which produces two main products: nutritious digestate and energy-rich biogas [24].

Anaerobic digestion is usually used for two purposes; it can be accustomed either to treat biodegradable wastes or produce saleable products (heat/electricity, soil amendment). Some energy production crops like sesame, soybean, palm fruit, groundnut kernel etc can be planted to be used for anaerobic digestion [13].

Anaerobic digestion systems can denigrate smells and vector attraction, minimize pathogens, reduce waste volumes, produce liquid and solid digestate, produce gas and reduce waste volumes. Anaerobically digesting organic carbon involves naturally occurring bacteria. Digestion occurs when organic materials decompose in an oxygen-free environment [6]. Anaerobic digestion comprises of several components of built systems which makes it to deliberately harness the natural process as depicted in Figure 3.



Source: Costa *et al.*, 2015

Figure 3: Components of Anaerobic digestion

Basics Anaerobic Digestion Process

Anaerobic digestion is an elaborate process having a consecutive number and corresponding steps carried out by microbes of different types. In this process, the undiluted substrate is pretreated and fed into an airtight digester under strict anaerobic conditions [1]. The airtight digester makes for the decomposition of the biodegradable matter into methane, carbon dioxide and other gases through multifaceted coordinated activities. The anaerobic digestion main reactions are expounded in the Figure 4.



Source: Ajay *et al.*, 2011

Figure 4: Main steps and pathways of dry anaerobic digestion process

Anaerobic digestion starts by some bacteria that hydrolyze complex organic polymers, such as carbohydrates, proteins, lipids and fats, into simple monomeric carbohydrates, amino acids, sugars and long chain fatty acids (LCFA) by extra cellular enzymes [1]. The monomeric compounds afterward changed into a mixture of volatile fatty acids (VFAs) and other minor products such as alcohol, carbon dioxide and hydrogen through fermentative anaerobic bacteria.

Factors Affecting Anaerobic Digestion

Some important operating factors tend to affect the degradation process of anaerobic digestion thereby enhancing the microbial activity and thus increasing the anaerobic digestion efficiency. The most important parameters are described below.

Temperature

Many researchers have undertaken work on the important effects of temperature on the microbial community, process kinetics and stability and production of methane. Decreased microbial growth, substrate utilization rates and biogas production occur during lower temperatures [10].

Though anaerobic digestion works perfectly practically in all climatic conditions, when the temperatures are low, the digestion process does not produce satisfactory result. At low temperature or cool climatic conditions, there arises need for a heating system to be installed or a bigger digester to be erected in order to increase the retention time [24].

Two important dissimilar ranges of temperatures are most competently used in the production of biogas, and each of these temperature ranges has different bacteria operating on them. The bacteria Mesophilic function optimally in the range of 90°F to 110°F while bacteria Thermophilic produce optimally at range of 120°F to 140°F. This bacterium (Thermophilic) kills more pathogenic bacteria but the maintenance cost of higher temperature is great. The stability of Thermophilic digesters is low [5].

Examination of digesters from Mesophilic and Thermophilic temperatures has dissimilar results: thermophilic digesters produce higher chemical oxygen demand (COD) removal and biogas production than the mesophilic digesters, and could sustain this at a higher organic loading rate. It is necessary that increase in methane production or yield through a thermophilic process should be balanced against the increased energy requirement for maintaining the reactor or digester at the higher temperature. This is not often an important consideration when the biogas produced is used for the generation of electricity, as heating the reactor is accomplished by routing the waste heat from the gas engines to heat exchangers within the reactor, and the engines generally produce more heat than the reactor requires [25].

pH

The pH is the most vital anaerobic digestion operational parameter. Anaerobic digestion is affected by alteration in pH because the hydrogen ion concentration has direct influence on microbial growth [1]. pH value of 6.8-7.2 is the ideal range for anaerobic digestion which is very narrow. The growth rate of methanogens is greatly reduced below pH 6.6, whereas an excessively alkaline pH can lead to disintegration of microbial granules and subsequent failure of the process [25].

When the pH of the anaerobic digestion system lowers and become acidic, lime can be added to raise the pH to the required level. In other case, sodium carbonate can also be used for pH adjustment [24].

Inside digesters operating normally, two buffering systems ensure pH persistence in desirable range, these are:

Ammonia-ammonium buffering system. When pH value decreases, ammonium ions are formed with releasing of hydroxyl ions while with increasing pH value more free ammonia molecules are formed. pH value of 10 is the center point around which pH value swings with the system.

Carbon dioxide (CO₂). Carbon dioxide (CO₂) is continuously produced during anaerobic digestion and released into gaseous phase. CO₂ is dissolved in the reactor solution as unchanged molecules when the pH value decreases while when the pH value increases, dissolved CO₂ form carbonic acid which ionizes and releases hydrogen ions [26].

Carbon to Nitrogen ration (C: N)

C: N ratio is the representation of the relationship between the amount of carbon and nitrogen in organic materials. This ratio (C: N) is a vital parameter for estimating nutrient and inhibition. Optimal C: N ratios in anaerobic digesters are between 16 and 25 [24].

When the C to N ratio is low, it causes ammonia accumulation and pH values exceeding 8.5 which is toxic to methanogenic bacteria [21]. Optimum C: N ratio of the feedstock materials can be achieved by mixing waste of low and high C: N ratio, such as organic solid waste mixed with sewage or animal manure.

Organic loading rate

The Organic Loading Rate (OLR) is a measure of the biological conversion capacity of the anaerobic digestion (AD) system. OLR represents the substrate quantity introduced into the reactor volume in a given time [24].

$$OLR=Q*S/V$$

Where:

OLR: Organic loading rate (kg substrate (VS)/m³ reactor

Q: Substrate flow rate (m³/day)

S: Substrate concentration in the flow (kgVS/m³)

V: Reactor volume (m³).

It is a vital control parameter for continuous systems, because when the system is overloaded it will lead to a significant rise in volatile fatty acids which can result in acidification and system failure.

Retention (or residence) Time

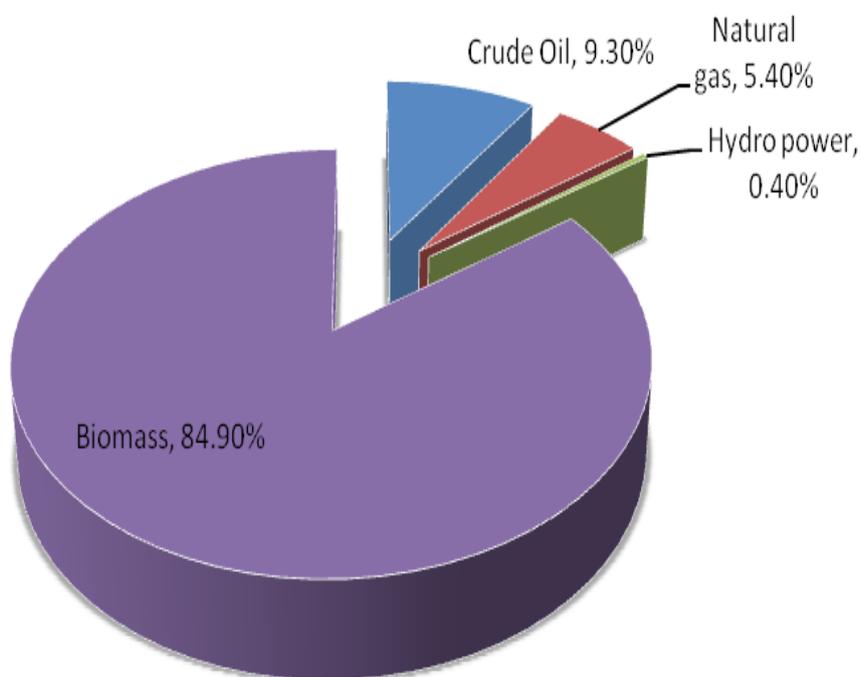
Process temperature, differing technologies and waste composition determines the required retention time for completion of an anaerobic digestion (AD). The retention time for wastes treated in mesophilic digester range from 10 to 40 days. In case of thermophilic digester, the retention time should be lower. For a high solids reactor operating in the thermophilic range, the retention time is 14 days [21].

Hydraulic retention time (HRT)

Hydraulic retention time (HRT) is the average time which a given volume of sludge remains in a digester. This is one of the most important design parameters affecting the economics of a digester [5]. The hydraulic retention time (HRT) required allowing complete anaerobic digestion reactions vary with different technologies, process temperature and waste composition. A hydraulic retention time (HRT) range of 10 to 40 days is recommended depending on digester type and solids content in the feedstock.

BIOGAS PRODUCTION IN NIGERIA

Majority of Nigerian population engage in agricultural production with more than 70% of the farmers being smallholder farmers [19]. Almost 48% of the total population of Nigeria lives in the rural area and majority of the people live below the poverty line [19]. Figure 5 shows the energy consumption in Nigeria. Traditional biomass (wood fuel and charcoal) accounted for 85% of total energy consumption which has contributed to desertification, deforestation and erosion in the country.



Source: IEA (2012)

Figure 5: Energy consumption in Nigeria

Identified feedstock substrate for an economically feasible biogas production in Nigeria have been studied to include cow dung, water hyacinth, cassava leaves, water lettuce, processing waste, solid waste, urban refuse, agricultural sewage and residues [14]. Therefore, putting the large quantities of biomass resources that are mostly in the form of agricultural wastes and residues which are currently disposed by burning or dumping, to energy production could potentially increase the energy supply thereby increasing energy mix and balance in Nigeria [19].

According to Simonyan *et al.* (2013), it is estimated that Nigeria generates fresh animal wastes of 227,500 tons daily [19]. But since 1 kg of fresh animal waste can produce 0.03 m³ biogas, which means Nigeria can potentially generate daily about 6.8 million m³ of biogas through animal waste. Furthermore, municipal solid wastes (MSW) of 20 kg per capita have been evaluated to be produced annually in Nigeria, but these waste (municipal solid waste) generations will continue to increase with increasing urbanization and industrialization. Therefore, the production of biogas from these wastes will be a profitable means of eliminating or reduction of waste menace and nuisance of urban wastes in many cities by recycling of the wastes [3].

	Type	Source
A.	Animal dung	Cow
		Buffalo
		Chicken
		Pig
		Duck
B.	Household wastes	Kitchen wastes
		Night soil
C.	Crop residues (air dry)	Corn stalk
		Rice straw
		Corn cobs
		Peanut shells
		Baggage
		Grass trimmings
D.	Industrial wastes	Breweries
		Wineries
		Bakeries
		Confectioneries
		Distillers
		Tea processing factories
		Noodles factories
		Other industrial organic waste water

Source. J. F. K. Akinbami et al., 2000

Table 3: Available biogas substrates

The agricultural wastes and residues produced in Nigeria are given in the Table 3.

The appropriate biomass conversion technology is influenced by several factors such as type and quantity of biomass feedstock, the desired form of energy to be produced i.e. end-use requirements, economic considerations, project specific factors, environmental standards. Furthermore, the biomass conversion depends on the use, material, size and shape of particles; it also depends on gas flow and types of reactors. The technology for biomass conversion should correspond to the type of biomass to achieve optimum outcomes [19]. Biomass can be converted through thermo-chemical and biochemical conversion pathways.

When biogas is produced in Nigeria from biomass, it would be suitable for various fuel requirements in the household, industrial and agricultural sectors such as in cooking, lighting, water heating, running refrigerators, water pumps, and electric generators domestically. Industrially it could be utilized in drying rooms, running of internal combustion engines for shaft power needs and in

small-scale industrial operations for direct heating applications such as in scalding tanks. The importance of biogas can be used agriculturally on farms for drying crops, pumping water for irrigation and other purposes.

Conclusion

Due to the increasing population, the epileptic power supply experienced in almost all parts of Nigeria, and the increasing cost of fuels, there is the need for exploration of other power sources. One of such source of power is the biomass production. There exist much opportunities for exploitation of different types of biomass in Nigeria with an estimated 2.01 EJ (47.97 MTOE) biomass residues and wastes annually through the anaerobic digestion of agricultural waste. This process of biogas and sludge production with agricultural value offers an alternative and efficient method of controlling agricultural wastes decay and littering of the environment, enhanced food production and using slurry from biogas generation as fertilizer. The conversion of agricultural wastes to energy will be rewarding, considering the large quantity of agricultural waste available in the country as a result of the frequent agricultural activities carried out by majority of the populace. Even though the usage of bioenergy in Nigeria has not received tangible attention because of the over dependence on crude oil, the future generation will have to look for alternate source of power because of the already depleting crude oil. The energy problem in Nigeria will be a forgone issue if the abundant biomass resources in the country is tapped and used to generate electricity. Nonetheless, there have been some programs by government towards boosting the energy mix within the country for electricity production through renewable sources. It is hoped however, that the laudable programs and policies on bioenergy will be given more attention.

Acknowledgement

This paper was supported by the Department of Agricultural and Bio Resources Engineering under the supervision of Post-graduate programme, University of Nigeria, Nsukka, Enugu state, Nigeria.

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