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Biogas Generation as a Renewable Energy - An Overview

[1]Oladeji, J.T., [2]Ogunsola, A. D. & [3]Balogun, A. O
Mechanical Engineering Department, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
Department of Mechanical, Automotive and Production Engineering, Elizade University, Ilara-Mokin, Nigeria
[1]Correspondence Author: - jtoladeji@lautech.edu.ng

ABSTRACT

Energy is an important factor, if not the most critical factor in developmental activities of any nation. The measure of level of social-economic growth and standard of living of the people of any nation are largely energy dependent. The growing world population, industrialization, technological advancement and transportation had brought energy demand under an increased pressure. This review presents the summary of biogas for energy generation, the fundamental principles and application of biogas production as well as some of the factors that can affect production of biogas to produce bio-fuels. Some of the factors examined among others were the temperature, pH of the substrate, nitrogen inhibition and the retention time. The study concluded that all the factors and variables examined in one way or the other had effects on biogas production and there exists optimum or threshold value for each feedstock depending on the operating conditions.

Keywords: - Bio-fuel, Biogas, Biomass, Char, Chemical Composition, Energy, Visualization, Concepts In Learning.

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1. INTRODUCTION

Energy is an important factor in development since it stimulates and supports economic and social development. Petroleum based fuels are finite in extent and should be regarded as depleting assets. The demand for energy being an important factor to global prosperity has increased over the years because of the increasing world population and expansion of global industries, especially food and agricultural industries (Oladeji, 2012).

The world's energy markets rely heavily on the fossil derived fuels whose reserves are finite (Agbontalor, 2007). Currently, 85% of the world's energy demand is met by combustion of fossil fuels which are depletable. Furthermore, the global energy demand is expected to grow by about 50% by 2025, the major part of this increase coming from rapidly emerging countries (Agbro and Ogio, 2012). Therefore, efforts should be oriented to search for new sources of energy. More importantly, the clamour all over the world for the need to conserve energy and the environment has intensified, as traditional energy resources continue to dwindle, while the environment becomes increasingly degraded resulting in health hazards to both human and ecology (Oladeji, 2011a; and Omer, 2007). Furthermore, there is the urgent need to generate alternative source of energy, which must not only be renewable, but must not pose any hazard to both humans and ecology (Oladeji, 2012). In this regards, agricultural residues in form of biomass can play a significant role in biomass energy generation (Oladeji, 2011a; Titiladunoye, 2002). As a result of scarcity of wood fuel in many parts of the developing world, an increasing number of people have been forced to turn to straw, crop stalk, animal dung and other agricultural residues as an alternative source of cooking and heating (Aremu and Agarry, 2013).

These residues often discarded or burnt as wastes occur in large amounts and they have the potential to be an important source of fuel for many people in rural areas (Jekayinfa and Scholz, 2009). Agricultural biomass waste, if converted to energy can substantially displace fossil fuel, reduce emission of greenhouse gases and provide energy to some 1.6 billion people in the developing countries which lack access to electricity (El-Saeidy, 2004). Therefore, the aim of this study is to make comprehensive review on biogas generation from biomass. In addition, those factors that have effects on the production of biogas through the process of anaerobic digestion of biomass residues were examined

2. METHODOLOGY

The method adopted for the study involved extensive literature review on the subject matter. Sources used included internet, previous reports and publications of notable researchers (the present author inclusive) on biomass, particularly on production of biogas from agricultural and animal residues.

2.1 Biomass

The biomass is generally applied to organic materials and these include residues from crops and plant materials grown for non-food use. Agricultural residues and animal wastes are increasingly being diverted for use as domestic fuels to displace fossils fuel and reduce environmental pollution and reduce emission of greenhouse gases (Aremu and Agarry, 2013). Biomass resources include various natural and derived materials, such as woody and herbaceous species, wood wastes, bagasse, agricultural and industrial residues Agbro and Ogie, 2012. Others are waste paper, municipal solid waste, sawdust, bio-solids, grass, and waste from food processing. Also in the cluster are animal wastes, aquatic plants and algae and so on (Oladeji, 2011b).

2.2 Advantages Of Biomass For Energy Production

There are a lot of benefits to be derived from using biomass for energy production. Among these benefits are:

i. They are readily available in the rural areas, where petroleum products are not always available and affordable.
ii. They serve as a useful way of waste disposal.
iii. Their use will help to reduce rate of deforestation as the rate of felling of trees in the forest will be greatly reduced (Adekoya, 1989).
iv. Their use will promote clean environment as less pollutants are deposited into the atmosphere, thereby reducing the green house effect (Wilaipon, 2009).
v. Their use will serve as additional way of generating income to farmers in rural areas, because once a market has been established, the residues may as well acquire a monetary value Oladeji (2011b).

2.3 Limitations Of Raw Biomass As Alternative Fuel

It is observed that several kinds of agricultural residues and animal wastes are available and ready to be utilized as fuels. However, agricultural residues in their natural forms will not bring a desired result because they are mostly loose and of low density materials in addition to the fact that their combustion cannot be effectively controlled (Oladeji, 2011a). Other draw backs are higher moisture content and lower energy density. Besides, the low bulk density and dusty characteristics of the biomass, there are also problems that are associated with their transportation, handling and storage (Husan, et al., 2002). Therefore, there is the need to transform these residues into forms that will make their combustion easy and more efficient. One of the methods through which these residues can be transformed is generation of energy through biogas production.

3. BIOGAS PRODUCTION

One of the methods through which agricultural residues and even animal wastes can be converted to useful biomass energy is through the production of biogas. One way of producing biogas is through the process of anaerobic digestion. Anaerobic digestion is a natural process that converts biomass to energy in the absence of oxygen. The anaerobic process removes a vast majority of the odorous and significantly reduces pathogens present in the slurry (Wilkie, 2000).

The use of rural wastes for biogas generation, rather than directly used as a fuel or fertilizer, offers several benefits such as the production of energy resource that can be stored and used more efficiently, the production of sludge that retains the fertilizer value of the original material and the saving of energy required to produce equivalent amount of nitrogen-containing fertilizer by synthetic process (Salunkhe, *et al*., 2012).

Biogas production is a profitable means of reducing or even eliminating the menace and nuisance of urban wastes in many cities in Nigeria (Akinbami, 2001). Consequently, biogas can be utilized in all energy consuming applications designed for natural gas.

3.1 History of Biogas Production

The discovery of biogas can be first traced back to 17^{th} century when Van Helmot noticed flickering lights beneath the surface of swamps and connected it to a flammable gas produced by decaying organic matter (Herringshaw, 2008). Also ancient Persians observed that rotting vegetables produced flammable gas (Ciobala, 2009). In 1859, Indians built the first sewage plant in Bombay (Ioana and Ciobala, 2010). Marco Polo has mentioned the use of covered sewage tanks in China. This is believed to go back to 2,000–3,000 years ago in ancient China. The idea for the manufacturing of gas was brought to the UK in 1895 by producing wood gas from wood and later coal. The resulting biogas was used for gas lighting in street lamps and homes (Ioana and Ciobala, 2010).

The techniques used for the conversion of organic materials to biogas have been in existence for many years. Biogas generation has been applied to meeting the energy needs in rural areas as it is been done in England, India and Taiwan. In the United States, there has been considerable interest in the process of anaerobic digestion as an approach to generating a safer clear fuel as well as source of fertilizer (Garba and Sambo, 1995).

3.2 Residues That Had Been Used to Produce Biogas

Many residues and wastes had been used to produce biogas by different researchers. Notable among these biomass residues are spent grains (Alade and Osuolale, 2012), livestock manure (El-Hadidi, 1999), poultry droppings using corn cob and waste paper as co-substrates (Aremu and Agarry), and palm oil effluents (Odeyemi, 1995). Other residues that can be used for biogas production in Nigeria according to Akinbami *et al* (2001) are water lettuce, water hyacinth, animal dung, cassava leaves and urban refuse.

3.3 Advantages of Biogas Generation

Production of biogas offers the following advantages, especially to the rural communities:

i.) There will be reduction in time spent by rural women on production of energy for household chores

ii.) The anaerobic plants are modular. They are made up of small units, which can be added to or taken as waste streams or volumes change (e.g. with increased recycling) and are therefore more flexible and can operate at a smaller scale than mass burn incinerators

iii.) Anaerobic digestion plants are quicker to build and set up as equipment/plant is simple and easy to construct from locally available materials and its operation does not require special skills.

iv.) Gas production enhanced energy supply decentralization such that rural communities can produce biogas to meet their fuel needs

v.) Construction of biogas plants can help to create new jobs, thus stimulating the rural economy.

vi.) Standard of living of the rural populace will be raised.

3.4 Products of Anaerobic Digestion

Biogas is essentially a mixture of methane and carbon dioxide, produced by the breakdown of organic waste by bacteria without oxygen (anaerobic digestion). It contains methane and carbon dioxide oxide with traces of hydrogen sulphide and water vapour. It burns with pale blue flame and has a calorific value of between 20 - 30J/m^3 depending on the percentage of methane in the gas (Sagagi, et al., 2005). Generally, biogas is a mixture of gases that is composed chiefly of Methane (CH_4): 40-70 vol. %, Carbon dioxide (CO_2): 30-60 vol. %. Other gases are Hydrogen (H_2): 0-1 vol. % and Hydrogen Sulphide (H_2S): 0-3 vol. %\

3.5 Uses of Products of Biogas

The use of biogas as an energy source has numerous applications. Biogas is suitable for practically all the various fuel requirements in the household, agriculture and industrial sectors. Highlighted in sections 3.5.1 to 3.5.2 are some of the uses of products of biogas

3.5.1 Methane

Methane (CH_4) is the main component of biogas, representing the energy produced from the bio-conversion of wastes. This energy is recovered by using the gas to generate electricity, thermal energy as well as transportation fuel. Domestically, it can be used for cooking, lighting, water heating, refrigerators, electric generators and water pump. In agricultural sector, it can be used in small scale industrial operations for direct heating applications such as in scalding tanks, drying rooms and in the running of internal combustion engines (Kristoferson and Bolkalders, 1991).

3.5,2 Carbon-dioxide

Carbon dioxide (CO_2), the other major component of biogas, has several uses when separated from the total gas stream. This option is exercised when there is a market for the products and an economic return is indicated relative to the capital equipment required to produce them. The standard uses of CO_2 are for carbonation of beverages and for dry ice production. Dry ice is used in transportation of frozen perishables. Chipped dry ice replaces grit and sand used in sandblasting operations without polluting the immediate environment. Additional uses include freeze tunnel applications for meat, fish, vegetable, and fruit processing. As a supercritical fluid, CO_2 is used as an extraction solvent in the food and pharmaceutical industries for products such as coffee, tea, tobacco, hops, corn oil, flavours, and colours. Its use is also recommended in industrial processes and for in-situ remediation of halogenated hydrocarbons and other solvents (Adebayo and Jekayinfa, 2012).

4. FACTORS AFFECTING GENERATION OF BIOGAS

The quantity and quality of products of anaerobic digestion of biomass depend on a number of factors. The yields depend essentially on the amount and nature of the fermentation, temperature, type of digester, pH of the substrate, nitrogen inhibition and the retention time. Others are physical and chemical characteristics of the biomass (feed stocks), stirring rate as well as specific operating and environmental conditions (Adebayo and Jekayinfa, 2012). Also, the amount of gas produced through anaerobic digestion is a function of the size of the bio-digester, its feeding regime and addition of substrates. Some of these factors that can affect the amount of gas produced of are discussed in sections 4.1-4.8

4.1 Retention Time

Retention time, which is also known as hydraulic retention time (HRT), is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. It represents the time period for which the fermentable material remains inside the digester. This period ranges from 35 days to 50 days depending upon the climatic conditions and location of the digester. The longer retention period needs larger size digester and it allows more complete digestion of feed. It is found that the biogas production per unit volume of digester is high when its diameter to depth ratio ranges from 0.66 to 1. Retention time is the most important factor controlling the conversion of solids to gas. It is also the most important factor in maintaining digester stability. Solid retention time is calculated as the quantity of solids maintained in the digester divided by the quantity of solids wasted each day (Adebayo and Jekayinfa, 2012). It is depicted by (1)

$$SRT = \frac{(V)x(Cd)}{(Q\,w)x(Cw)} \quad (1)$$

In this formula, V is the digester volume; C_d is the solids concentration in the digester. Q_w is the volume wasted and C_w is the solids concentration of the waste. In general, optimum retention time range is between 1 to 35 days in full scale treatment systems and 10 to 20 years in landfills (Salunkhe, *et. al.*, (2012). Under optimum condition 80-90% of total gas production is obtained within a period of 3-7 weeks.

4.2 Addition of Substrates

This is also known as co-digestion. Co-digestion of manure with other substrates such as industrial wastes, grass clippings, food industry wastes, animal by-products (slaughterhouse waste), or sewage sludge can result in multiple benefits. This includes an improved nutrient balance of total organic carbon, nitrogen, and phosphorous, which results in a stable and maintainable digestion process and good fertilizer quality (Singh, 2010). Co-digestion also improves the flow qualities of the co-digested substrates. In addition, the economics of digester projects benefit from the increased gas production due to co-digestion and also from the income generated from tipping fees (i.e., waste disposal fees that are generally based on a per volume or weight basis). Many substrates are generally used as feedstock in biogas plants and the potential for biogas production varies with feedstock. Generally animal waste, human waste, kitchen waste and some crop residues are used in small scale biogas plants. Gas production rate varies with the type of substrate used in the biogas plant. Normally 1 m^3 of biogas is enough to cook three meals for a family of 5-6 members. For example Aremu and Agarry, 2013 observed enhanced biogas production from poultry droppings when corn cob and waste paper were used as co-substrates.

4.3 Operating Temperature

Digesters can function at ambient temperatures in warmer climates, but with a lower biogas output than heated digesters. In some applications and in colder environments, digesters are heated. Anaerobic fermentation is in principle possible between 3^{o}C and approximately 70^{o}C. Differentiation is generally made between three temperature ranges. These temperatures are the psychrophilic temperature, the range, which lies below 20°C, the mesophilic temperature, which ranges between 20^{o}C and 40^{o}C and the thermophilic temperature range above 40°C. Anaerobic digestion under thermophilic conditions generates gas in a shorter amount of time than anaerobic digestion under mesophilic conditions. However, a higher percentage of the gross energy generated is required to maintain thermophilic conditions within the reactor. The extra heat is either extracted from the gross waste heat recovery in an engine or recovered from effluent. Many researchers (Aremu and Agarry, (2013); Salunkhe, *et. al.*, (2012); Herringshaw, (2008); Ioana and Cioabla (2010) noted that mathogens are usually inactive in extreme and low temperatures. The optimum temperature is 35^{o}C. However, if the ambient temperature goes down to 10^{o}C, the gas production will virtually stop. Satisfactory gas production takes place in the mesophilic temperature within the range of between 25^{o}C and 35^{o}C, while for thermophilic temperature; the optimum range is 50^{o}C – 60^{o}C.

4.4 Types of Biomass Feedstock

The rate and quantity of biogas that can be generated depend on the types of biomass feedstock. This is because biomass feed stocks lend themselves to process of anaerobic digestion differently. According to Singh (2010), while some biomass feed stocks lend themselves easily; others do so with some degree of difficulty. The ease or otherwise of each biomass feedstock is measured through the amount of biogas generated when subjected to the same operating conditions. This assertion was confirmed by the work of Harilal *et al* (2012), when three biomass feed stocks namely cattle dung, pig dung and poultry droppings were subjected to anaerobic digestion under the same operating conditions. The result of the experiment showed that cattle dung produced 0.092 m^3 of biogas per kg of cow dung, while pig dung produced 0.10 m^3 per kg of pig dung. The highest generation of biogas was produced by poultry droppings, which is 0.16 m^3per kg.

4.5. pH Value

pH value indicates the degree of acidity or alkalinity of a solution. The pH value is represented as the logarithm of the reciprocal of the hydrogen ion concentration in gm equivalent per litre of solution. The pH value depends on the ratio of acidity and alkalinity and the carbon dioxide content in the digester, the determining factor being the density of the acids. pH value in the range 0-7 represents acidic solution and in the range 7-14 indicates the alkaline solution.

A digester containing a high volatile-acid concentration requires a somewhat higher-than-normal pH value. If the pH value drops below 6.2, the medium will have a toxic effect on the methanogen bacteria. The methane-producing bacteria live best under neutral to slightly alkaline conditions. Once the process of fermentation has stabilized under anaerobic conditions, the pH will normally take on a value of between 7 and 8.5. Due to the buffer effect of carbon dioxide, bi-carbonate (CO_2– HCO_3^-) and ammonia-ammonium (NH_3– NH_4^+), the pH level is rarely taken as a measure of substrate acids and/or potential biogas yield.

4.6 Loading Rate (Regime)
Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. In the similar manner, if the plant is underfed, the gas production will also be slow. Optimum loading rates vary with different digester and their sites of location (Adebayo and Jekayinfa, 2012)

4.7 Stirring Rate
This is also known as agitation. This becomes imperative, especially when solid materials are present in the digester as this may impede gas generation through the formation of scum. In a situation if the scum hardens, it disrupts the digestion process, thereby causing stratification. This problem is much greater with vegetable waste than with manure, which will tend to remain in suspension and have better contact with the bacteria as a result. Continuous feeding causes fewer problems in this direction, since the new charge will break up the surface and provide a rudimentary stirring action. In such situation, agitation can be done either mechanically with a plunger or by means of rotational spraying of fresh influent.

4.8 Available Nutrient Concentration

In order to grow, bacteria need more than just a supply of organic substances as a source of carbon and energy. They also require certain mineral nutrients. In addition to carbon, oxygen and hydrogen, the generation of bio-mass requires an adequate supply of nitrogen and sulphur. The major nutrients required by the bacteria in the digester are N_2, P, S, C, H_2, and O_2 to accelerate the anaerobic digestion rate. Thus it is necessary that the major nutrients are supplied in correct chemical form and concentrations. The carbon in carbohydrates supplies the energy and the nitrogen in proteins is needed for building of growth of bacteria. The correct ratio of carbon to nitrogen will prevent loss of either fertilizer quality or methane content.

5. CONCLUSION

From the review study, the following conclusions among others can be drawn:-

- Anaerobic digestion is a natural process in which bacteria convert organic materials into biogas.
- The products of anaerobic digestion are predominantly methane and carbon dioxide.
- Organic wastes and residues such as dead plant and animal materials, animal dung, and kitchen wastes can be converted into a gaseous fuel called biogas.
- Biogas can be utilized in all energy consuming applications designed for natural gas.
- The retention period to obtain maximum biogas yield ranges from 35 days to 50 days depending upon the climatic conditions, biomass feed stocks and location of the digester.
- Co-digestion of manure with other substrates such as industrial wastes, grass clippings, food industry wastes, animal by-products (slaughter house waste), or sewage sludge usually results in higher biogas yield.
- Satisfactory gas production takes place in the mesophilic temperature within the range of between 25^{o}C and 35^{o}C, while for thermophilic temperature; the optimum range is 50^{o}C – 60^{o}C.
- The rate and quantity of biogas that can be generated depend on the types of biomass feedstock. This is because biomass feed stocks lend themselves to process of anaerobic digestion differently.
- The methane-producing bacteria live best under neutral to slightly alkaline conditions.
- The pH value of between 7 and 8.5 will give maximum biogas yield.
- During anaerobic digestion, stirring becomes imperative in order to prevent formation of scum which may impede gas generation.

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