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# Anaerobic Digestion for Sustainable Energy: A Brief Review

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*Abstract*— **This paper presents a review on different aspects influencing the development of household anaerobic digesters. Biogas technology has recently been considered as one of the few most promising renewable and sustainable energies. However, there exists certain challenges to household digester's dissemination. Some of these challenges are very critical to the appreciation of anaerobic digestion processes as well as systems. The type of waste, feeding regime, temperature, pressure, retention time, hydrogen ion concentration and the carbon-to-nitrogen ratio are considered to be very important factors for optimum anaerobic digestion processes. The plant sustainability and the quality of anaerobic digestion bi-products are also considered very important during design and implementation stages.**

*Index Terms*—**Anaerobic digestion, Renewable energy, Economic development, Bio digester.**

## I. Introduction

THE lack of consistent and adequate energy supply in third world countries has been one of the major barriers to economic development of the African, Asian and American regions. According to Zikovic and Dizdarevic [1], an increased availability of energy in quality and quantity terms contributes to industrialization of poorer societies by advancing their incomes through refinement of their exported products. Since the industrial revolution (for so long), the world's economy has been driven by the use of fossil fuels such as oil and coal, and the use of such fuels has largely contributed to the destruction of the earth as well as the human race [2],[3]. Recent studies have suggested that with the current consumption rate of natural fossil fuels as source of energy would lead to complete depletion of these reserves and therefore, leaving billions of people cold and hungry [4]. In addition to these studies, studies by Kennedy [3] reported that the amount of natural resources used for the production of electricity and generation of energy in developing countries has increased dramatically in recent years. In countries such as Nigeria and the Democratic Republic of Congo, electricity is a major issue that needs to be addressed. In order to resolve this issue, Nigerian and Congolese people decided to make use of diesel generators; noisy machines that highly contribute to sound pollution in residential areas. With the price of petrol (diesel) rising for the last 10 years, some of the people using generators cannot afford to use these machines on a continuous basis for either domestic or business purposes (see Fig. 1) [3]. As a solution, it was judged responsible to look into new and affordable ways of generating energy, and one of the most promising technology has been biogas technology. Domestic biogas plants may be seen as future replacement to fuel generators and especially when petroleum reserves run out. Deciding on implementing domestic biogas plant requires careful studies of the factors affecting biogas generation as well as its benefits. This paper discusses some of the factors contributing to the development of biogas technology.

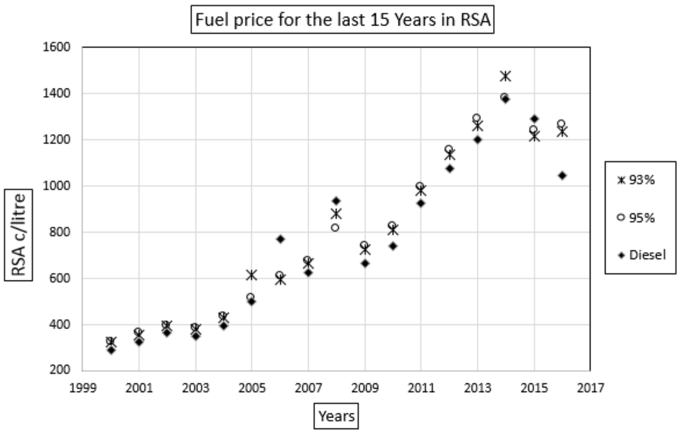


Fig. 1. South African Petrol Price Distribution

## II. Literature Review

Biogas is a form of renewable energy that is generated from the decomposition of organic matter. Recent studies in terms of renewable energies showed that biogas technology is increasingly becoming one of the attractive source of energy for most countries in the world. In most part of Asia, biogas is being used as source of energy in rural cities [5]. Countries in that part of the world show a more aggressive approach to the implementation of this technology when compared to countries in other regions. Cheng et al. [5] reported that China has been the leading party with an interest growth of 34 % in the past 40 years. Between 1960 and 2011, neighboring countries such as India had implemented more than 4.3 million rural digesters while the Nepal, Bangladesh, Vietnam and Cambodia installed more than 500 000 domestic digesters among them. In comparison to Asia, only 4 countries in Latin-America had implemented a structured biogas program prior to 2010. Those countries are Peru, Bolivia, Columbia and Guatemala. After the global

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economic crisis of 2008, additional countries such as Argentina and the Nicaragua started assessing biogas potential for national biogas programs implementation [5],[6]. According to Rakotojaona [6], the level of biogas technology used in Africa remained extremely low prior to 2008, despite the fact that some of the first digesters were installed in 1950. In 2012, the Rwandan government committed to have more than 100 000 household digesters installed before 2017 for energy generation purposes while that of Kenya settled for 8000 domestic plants before 2020 [6]. Also studies in Uganda has shown that biogas technology has a bright future in developing countries such as Uganda where 92% of their energy demands is satisfied by wood and charcoal. Having such wood consumption rate will leave Uganda importing wood fuel as early as 2020, therefore investing in biogas technology provides an escape route in terms of energy crisis and climate change [7]. In addition to the interest from developing countries, the so-called developed countries by the like of the Germany, United State or United Kingdom have also shown interest in biogas technology. For example, 0.5% of electricity in the United Kingdom is produced from biogas fuels while in the United State, biogas fuels account 1% for electricity generation [5].

### *A. Biogas production process*

Anaerobic digestion is a chemical process previously used in the wastewater treatment industry [8]. Anaerobic digestion is defined as a process used to chemically decompose organic matter in the absence of Air [9]. Properly handled decomposition of organic matter leads to the production of biogas which in turns is a combination of methane, hydrogen sulfide and ammonia gases. According to Igoni et al. [9], a variety of organic raw materials decompose into biogas. Human, animal waste, crop residue, agro-industrial waste and other biomass materials may be utilized to an advantage of generating sustainable and affordable energy. During anaerobic digestion, organic matter usually placed in an airtight pressure vessel decays in the presence of water or hydrogen to produce biogas [7]. Itodo and Philips [10] defined biogas as "a methane-rich gas produced from an anaerobic decomposition of organic materials in a biological-engineering vessel". Usually, the decomposition of organic matter in the absence of air occurs by means of micro-organisms at a temperature near the ambient temperature and atmospheric pressure or by means of chemical or physical reactions at elevated temperature. The distinction between methods mainly depends on the accepted polluting impacts of the environment. Irrespective of the method, anaerobic digestion is simplified into four consequent biochemical transformations which are hydrolysis, acid-genesis, acetone-genesis, and methane-genesis. During methane-genesis, the products of primary processes are converted into methane. During Hydrolysis, 100% COD suspended organic matter are decomposed into Fatty acids and Amino-acids and Sugars. These amino-acids are further decomposed into intermediate products such as Propionate or Butyrate during the acid-genesis phase while resulting products of acid-genesis and hydrolysis are converted into Hydrogen and Acetate during the acetone-genesis phase [11]. Biogas produced through anaerobic decomposition have a typical concentration of 50% or more methane gas depending on the effectiveness and duration of the process. Table I gives a typical composition of biogas resulting from an anaerobic process. Data produced by Igoni et al. [9] correlate with data provided by Otim et al. [7] and therefore may be used as basic composition for biogas in a design of the digester.

TABLE I
TYPICAL BIOGAS COMPOSITION [7]

| Composition | Percentage | Properties and Remarks |
|---|---|---|
| $CH_4$ | 55 - 70 | Main source of energy, lighter than air and has ignition temperature of approximately 700 °C with specific gravity of 0.86 and a flame factor of 11:1. Its flammability in air is 6-25 % (safer than other gasoline) |
| $CO_2$ | 30 - 45 | Green gas. Use for Photosynthesis |
| $NH_3$, $H_2S$ and others | 1 - 5 | - |

### *B. Benefits from biogas technology*

Investment in biogas production around the world is highly motivated through social objectives such as health and safety from proper management of human, agricultural or industrial wastes by lowering indoor air pollution resulting from wood fires. When burning substances such as coal, wood, and charcoal; a large amount of carbon monoxide and other chemicals that cause health detrimental are released into the atmosphere. The world health organization (WHO) has linked exposure to indoor smoke with critical illnesses such as asthma, tuberculosis, lung diseases or a variety of cancers [12]. According to the South African Western Cape province, approximately 1.8 million people die annually from exposure to indoor black carbon [13]. In addition to health and safety, biogas is also seen as a way of mitigating climate change. This is attributed to the fact that it can be used as a substitute for commonly used sources of energy with larger impacts on the atmosphere such as coal, wood, nuclear and others. The use of anaerobic digestion for biogas production from solid waste can reduce greenhouse gas (GHG) emissions. Waste treatment management systems stores manure and entrap gas methane (greenhouse gas) that could have been released into the atmosphere. Also, the biogas generated by anaerobic digestion process may replace the use of fossil fuels. These fuels generate a high amount of GHGs. In rural areas, biogas can be used as an alternative to wood fuel and in this way reduces the threat of deforestation. Biogas can also be used in the transport industry as bio-fuel in car or jet engines [14]. In South Africa, the Renewable Energy Feed-In Tariff acts as an incentive for electricity supply from biogas to substitute conventional electricity supply since the country has low electricity costs according to authors in [13]. An increase in electricity production from renewable sources, such as biogas or geothermal, will not only reduce the demand for fossil fuels, but it will provide a measure of stability in the electricity environment. According to Rutz et al. [15], phytotoxic substances contained in solid wastes usually, cause necrosis and sclerosis to growing plants.

Through anaerobic degradation, phytotoxic acids are degraded and dry matter content is decreased. Therefore, digested manure may be applied to the agriculture industry as natural soil fertilizers. It also contributes to a double effect of saving water resources while growing organic plants. An increasing ammonia content in manure results in a faster-growing rate of organic plants. If the abortion of ammonia by the plants occurs at faster rates, excess ammonia is leached into the ground up the ground-water-level and this results to a complete failure of the photosynthesis process. Thus groundwater pollution through nitrate is prevented by slow release of ammonia in the atmosphere through anaerobic digestion. Anaerobic digestion is additionally considered as a method of controlling odors resulting from a premature release of hydrogen sulfide, carbon monoxide, and other substances into the atmosphere during landfill storage [16].

### *C. Sources of biogas*

Biogas has generally been produced from feedstocks such as manure slurries, wastewaters and agro-industrial wastes [17],[18]. So based on this elaboration, it can be said that biogas is a natural fuel produced by anaerobic digestion of municipal solid waste (MSW), industrial waste (human sewage) and domestic solid waste (such as food waste, manure, vegetable matter, animal dung, or crop residues [9], [19]. This paper only focuses on the potential of organic food waste in anaerobic digestion.

### *D. Organic food waste*

Food waste (FW) is the type of waste which consists of useless material resulting from cooking. This includes all organic materials such as fruits, food remain and etc. rejected during the entire process; from harvesting to cooking. Igoni et al. [9] describe food waste as being a combination of all organic matter with no direct value produced in the food consumption process. According to Curry and Pillay [20]; almost one-third of all food produced globally every year goes to waste. This is due to the level of difficulty required to biologically degrade its components. A difference in composition of FW yields to a difference in concentration of main components such as lipids, proteins, carbohydrates and cellulose which are difficult to dispose of. According to Arsova [21], the bio-methanation potential depends on the biochemical composition of FW but Curry and Pillay [20] suggested that determining accurately the percentage of lipids, carbohydrates and proteins in heterogeneous waste such as FW are quite a difficult task to perform due to the sensitive and dynamic nature of biological processes resulting from cooking or conservation processes. Additional research showed that waste systems with excess in lipids produces high methane content but requires long retention time. Systems with excess in proteins, on the other hand, have the fastest methanation process followed by systems with excess in cellulose and carbohydrates [21]. Despite having high methanation rates, systems with excess proteins and lipids experience inhibitory effects due to the volatile fatty acids (VFA) accumulation as well as the presence of nitrogen and ammonium. The presence of ammonium and nitrogen in these systems slows the hydrolysis process rate and therefore making them less efficient.

### *E. Factors affecting biogas production*

During AD, biogas is usually produced at different rates depending on the operating parameters of the reactor. Factors such as the internal temperature, Hydrogen ion concentration, moisture content, carbon-nitrogen ratio, mixing and organic loading rate plays an important role in the operation of AD systems.

#### *Temperature*

The operating temperature of the digester among other factors plays an important role during anaerobic digestion. The effect of temperature on the overall process is due to the fact that anaerobes used for organic decomposition are temperature dependent. According to Ramatsa et al. [22], there exist three temperature regions in which anaerobic fermentation can be achieved: (1) psychrophilic (10-20 $^oC$), (2) mesophilic (25-38 $^oC$), and thermophilic (44-57$^oC$). Most common temperature range used in anaerobic digesters are either mesophilic (with an optimum at 35 $^oC$) or thermophilic (with an optimum at 55 $^oC$). The rate of decomposition and gas production is sensitive to temperature, and in general, the decomposition is rapid at high temperature [20]-[36]. In biogas plant design, it is important to choose an appropriate temperature for operation since a variation of 1 $^oC$ can force organisms into dormancy state [9]. In order to avoid such variation, the operating temperature inside the digester is usually maintained by blanketing of the reactor or incorporation of automatic heating systems such as heating coils [23].

#### *Feedstock materials*

Different organic wastes have different biogas potentials depending on the process temperature. In order to assess this, Prasad [24] tested the potential of biogas production for cow, pig manure and chicken wastes at different temperatures. During the study, it was found that different digester inputs have different biogas potentials and the findings suggested that at room temperature conditions, cow dung has a high production rate while chicken waste has the slowest rate. After 9 days of hydraulic retention, Cow dung produced a considerable amount of burning gas compared to chicken waste which took 24 days to produce burnable gas. In order to assess the potentiality of digester inputs, the operating temperature of the digester was varied and its effect on the production rate was assessed. At mesophilic conditions, Cow dung produced burnable gas after 7 days which 2 days earlier compare to room temperature. Chicken waste in turn showed greater potential as it produced gas after 11 days compare to 24 at room temperature. Based on this findings, it concluded that thermophilic digestion is less efficient for anaerobic digestion of cow dung but very efficient for chicken waste [24].

#### *Substrate mixing*

According to Igoni et al. [9], mixing is an important operation for optimal anaerobic digestion. Mixing is solely used for the purpose of maintaining the temperature and the substrate concentration uniform as well as to prevent scum formation and solid deposition. Depending on the source of feedstock, particles have different sizes and therefore it is important to mix them. Small particles tend to provide better and more biogas compare to larger particles. This is due to the fact that methane-producing bacteria in smaller particles have better contact with the volatile solid [12]. According to Samer [25], intensive mixing results in an increase in retaining time and this occurs because the bacteria are not in contact long enough with the substrate.

*Moisture content*

Moisture content is essential for fermentation processes and therefore for optimum anaerobic digestion. From literature [9]-[39], it is known that water helps to restore the neutrality of the solution (increasing pH). In the study of the effect of moisture content on anaerobic methanation by Qu et al. [26], it was found that as moisture content increases, the methane production rate also increases. For a moisture content of 80%, the cumulate methane production increased by 60%. This increase was explained by the fact that cellulosic waste with high moisture content has an increased area of contact between the microbes, enzymes, and the substrates. An increase in attachment area enhances waste methanation and hydrolysis process.

*Effect of Carbon-nitrogen ratio*

Dioha et al. [27] stated that optimum gas production is achieved when the C-N ratio is about 25-30 to 1. This belief is also supported by many other researchers [9]-[39]. The concentration of carbon and nitrogen determines the performance of the anaerobic process because C and N constitute the source of energy to the microorganisms. C and N also contribute to the enhancement of microbial growth. Since the bacteria during fermentation use up the carbon in the substrate 25 to 30 times faster than the rate at which they convert nitrogen, the optimum ratio should, therefore, be within the range provided by Dioha et al. [27]. Excess Nitrogen causes the microbial populations not to grow and as a result of this, the process takes longer to decompose the available Carbon.

*Hydrogen-ion (pH) concentration*

According to Igoni et al. [9], the level and variation of pH in the material to be digested usually affects the fermentation process. This is due to the fact that anaerobic digestion is self-restrained by excessive acidity. For optimum digestion, the bacteria involved need to have a pH concentration value close to 7 as acid and base neutralizes each other. Experiments by Ozturk et al. [27], [28] showed that if the pH value decreases to 5, the gas production is significantly affected as the population of cellulolytic bacteria, amylolysis, and proteolytic organisms reduce as well. The production of volatile fatty acids during the initial phases of the process tends to depress the pH but further reaction between $CO_2$ and $H_2O$ tends to restore the neutrality of the solution [11]. In addition to this mechanism, the overall effect of the pH can be optimized by adding sufficient alkalinity to the solution (3000 mg/l) as suggested by Igoni et al. [9]. This alkalinity solution helps reduce the concentration of $CO_2$ by ensuring a high rate of methane production.

*Organic loading rate (OLR)*

From all factors affecting biogas production, the OLR is very important parameter due to the fact that this greatly affects the anaerobic digester's design process. This affection arises from the fact that OLR indicates a number of volatile solids to be fed into the digester during each cycle. The actual OLR depends on the types of wastes fed to the reactor because the types of waste determine the rate of decomposition [29]. Variations in the chemical composition of the influent and the loading rate cause an upset in the balance between methanogens and acid fermentation [9]. Research have been conducted on the effects of loading rate in biogas production. Aslanzadeh et al. [30] evaluated the effect of OLR and hydraulic retention time (HRT) by comparing single and two stage anaerobic processes using food waste. As a result of the study, it was found that the volume of the reactor in the two-stage system is reduced by 26% while the retention time is decreased by 65%. In addition to this finding, he stated that single-stage systems are limited by the OLR since high OLRs cause inhibition due to the level of the accumulated VFAs. Dermirer and Chen [31] supported the statement by saying that at high OLRs, two stage systems have HRT that is sufficient for the microorganisms to have enough time to degrade the substrate when the hydrolysis-acid genic tank operates in thermophilic conditions while the methanogenic tank is in mesophilic conditions for optimum operation. These conditions lead to the reduction in retention time of the overall process (from 80 days to 15 days maximum) [30],[32]. The statement was supported by the findings of Nickolausz' experiment. According to Nickolausz et al. [33], the rate at which the reactor is loaded has a major impact on gas production. They proved that alternating the feeding regimes of a reactor can lead to maximizing biogas production. This was achieved in 2 different experiments where the team compared the production rates of 2 similar digesters loaded using different rates. In one digester, organic matter was fed once per day while in the other one, organic matter was fed every 2 days. The results showed that the reactor fed once a day had a 14% $CH_4$ and a 16% biogas production increase while the other reactor had a 13% $CH_4$ and 18% biogas increase. According to Nickolausz et al. [33], this difference resulted from an environmental variation in terms of substrate concentration. This is explained by the fact that there is a fluctuation in the microbial community every single time the reactor is loaded, and therefore leading to different ways of degradation. If the feeding regime is varied, the amount of ammonium, nitrogen, and hydrogen supplied to the microbial communities is affected, thus resulting in alternating their activities [33].

## III. Conclusion

The key analyses in the development of domestic anaerobic digesters for the production of biogas from organic food waste have been reviewed. The study showed that different substrate materials have different biogas potentials depending on their moisture content and their densities. More slurry matter such as pig and cow dung are highly suitable for thermophilic digestion while the denser materials such as kitchen waste are suitable for mesophilic digestion. Anaerobic digestion is also affected by other factors such as substrate mixing, C-N ratio, hydrogen-ion concentration and feedstock loading rate. Systems operating with non-optimized factors such as intensive mixing and high feeding rate have high retention time and low biogas quality. Intensive mixing and high OLR result in an upset in the balance of between acid fermentation and methane-genesis; therefore, depressing the pH value. Depressing the pH results in an increase in volatile fatty acids which in turn requires more time for complete degradation yielding to high HRT. It is therefore recommended that operating factors of anaerobic digestion process be optimized when implementing AD systems.

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