

Development of a Biogas Plant with Electricity Generation, Heating and Fertilizer Recovery Systems

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ABSTRACT

This study is a review of the role of biogas from agricultural biomass in the energy transition in a multipurpose application for supply of electricity, heat energy and fertilizer to support agriculture. The global concerns and commitment to reduce greenhouse gas emissions and the related global warming has set in motion effort to identify and promote renewable energy sources like biogas. Biogas can be produced from any biodegradable biomass under suitable conditions making it possible for rural based smallholder farmers to effectively participate in the global energy transition to renewable and low carbon grid electricity. With development of decentralization of grid power generation, smallholder farmers can generate biogas and use it to run grid connected electricity generator to earn revenue and reduce the demand on grid s electricity. However many digesters fail and remain idle in developing countries due to lack of adequate operation and maintenance knowledge while conversion technologies available remain advanced and complex for the smallholder farmers. With proper process management, the digestate will substitute chemical fertilizers with additional financial benefits and fertility management. The farmers will also meet their entire heating requirements from a well-designed and sized biogas plant. The overall objective of this study was to identify measures and technologies that can be adopted by farmers to generate power for own use and export to the power grid while meeting other energy and farming requirements for sustainable agriculture. The study showed that biogas from agricultural wastes can play a leading role in the energy transition to green and low carbon sources for grid electricity, but a sustainable biogas system has to be multipurpose to make social economic sense to smallholder farmers. The study recommends modifications on bio-digesters and the use of the Stirling engine to generate electricity at farm level though other feasible conversion technologies are available. For viability of grid supply, state incentives like attractive feed in tariffs are necessary.

Key words: Biogas; Challenges of biogas production; Biogas production process; biogas engine; bio-digesters; electricity from biogas; fertilizer from biogas; Stirling engines; cogeneration.

1.0 Introduction

The challenges of heat and electricity generation, its sustainability, cost involved, environmental issues have generated interest in in alternative sources of energy and technology globally (Kabeyi & Oludalapo, 2020; Ndereba, 2014). Energy plays a critical role for economic growth and development, thus its availability as a key indicator as well as ingredient of economic growth of any country. Traditional energy though appropriate face different challenges that affect the economic growth and adaptation (Scriba, 1999). Majority of the in developing countries are smallholder farmers who rear livestock and undertake mixed farming (Chen et al, 2017). With low electricity penetration and poverty, access to grid electricity is limited, yet they still need electricity for several application and heat for cooking and other heating applications. As a result they rely on polluting fossil fuels, and wood which accounts for accounts for 61% of the total energy sources (Karuiki, 2009). Non-oil producing country also face the challenge of fossil fuel price instability and pressure on foreign exchange (Chen et al, 2017). This calls for a sustainable solution to save the forests and environment while to the majority rural households through biogas generation and use.

2.0. Global Status of Biogas as a Source of Energy

There has been a great drive to turn to green and renewable energy and reduce overdependence on the current traditional forms of energy production. Biogas generation has been presented among the top possible and sustainable solutions that can be easily rolled out with little resources and time (Kabeyi, 2020; Kabeyi, 2019). Hence, many attempts have been undertaken with a different concept of biogas plant being designed and implemented. However, a notable factor that affects the design and implementation of any biogas plant has been identified as the area of implementation. This means that different areas may call for different design and specification of a biogas plant as raw material and volumes are critical factors. Biogas digester has shown the ability to provide different solutions and possibilities to global concerns like expanding food production and supply, an alternative source of energy, handling of animal, human, industrial and municipal waste safely and beneficially (Hahn, 2015). Available technical data on biogas plants has been constrained to two main design; the fixed dome design and the floating dome design. This is mainly as a result of the massive use of the two design without attempts to continuously improve the biogas concept. However, there are new designs of biogas plants that are now being developed to ensure sustainability and viability of the idea. There is a growing need to develop a more economical, sustainable and practical biogas design in order to bridge the gap between the traditional energy sources with renewable green energy sources (Hahn, 2015). The biogas technology has not yet realized a portion of its potential in energy production as it is mainly hindered by high construction and operational costs (Barasa, 2020). Lack of urgency in implementing the biogas technology has mainly resulted from the availability of other non-expensive energy sources like firewood.

A study in China by Hahn (2015), identified different benefits of biogas production to enhance agricultural productivity and energy supply. From this study, a biogas digester has the capabilities of improving the rural living standard and income. Renewable energy produced by the biogas digester could be used for lighting, cooking, heating, powering diesel engines which in turn run machinery at home and even at schools besides running electric generators. In 2005, small household biogas digesters in the world were estimated to be around 16 million. Most of these digesters were in India and China. Statistics from India showed that biogas digesters replaced firewood weighing over 6 million tons in the year 1996 while China's 7 million biogas digesters were able to meet the country's 4% energy demands (Hahn, 2015). Statistical evaluation has shown that the highest number of biogas digester is operating below recommended and expected capacity, while others are dormant after construction (Scriba, 1999). This has been explained through poor or lack of technical management skills, economic and sociocultural issues. There exists a perception that the biogas financial maintenance cost may be low but the labor associated with the maintenance is high (Bond, 2011). Challenges facing the biogas technology adoption have been identified as; poor maintenance and management, lack or Low technological awareness, high installation cost, systems failure, lack or poor post installation support, lack of standards to follow in design, fabrication and installation and scarcity or lack of Scarce promotional activity to encourage technology adoption.

3.0. Biogas Production Process

Biomass, which is made up of large organic polymers, is broken down by microorganism and chemical into smaller molecules (Amigun, 2008). Hence, biomass is converted into biogas through anaerobic digestion, where the biogas consists of methane, carbon dioxide, wastewater, and digestate. Figure 1 below is a flow chart for biogas production.

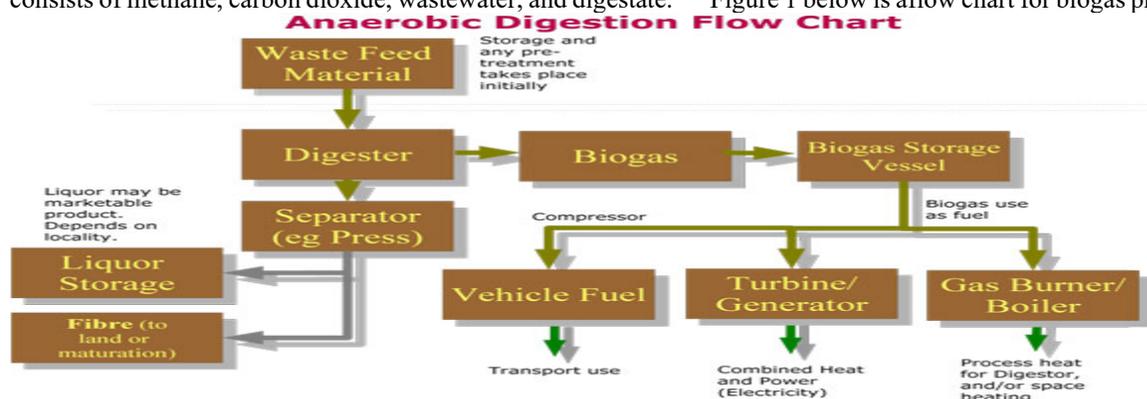


Figure 1: Fundamental steps of anaerobic digester (Amigun, 2008).

From figure 1, it is noted that biodegradable water upon bio digestion can be stored and put into several uses like heating in a burner, turbine generator or vehicular fuel, either at atmospheric conditions or may need compression.

There are four critical steps of anaerobic digestions are:

- i.) Hydrolysis
- ii.) Acidogenesis
- iii.) Acetogenesis
- iv.) Methanogenesis

2.4 Digester Instrumentation for optimum digester operation

i.) Temperature

Just like any other biological and chemical process, if more energy is applied in a reaction, the reaction is faster until the degradation point is reached. Hence a certain temperature range is critical to maximize the speed of reaction and the life of the organism. The commonly used microorganisms in an anaerobic digester are thermophiles that undergo thermophilic and mesophilic digestion. Thermophiles are efficient at temperature 45-80°C while mesophilic bacteria prefer 25-40°C (Bond, 2011).

ii.) Digester instrumentation

It is very critical to constantly measure the production level in any anaerobic digester to identify, biomass quantity, any abnormalities and the well-being of microorganism (Karekezi, and Kithyoma, 2007). In a system where biomass is added a continuously, measuring the gas produced helps in ensuring that the microorganisms are at their peak digestive capability (Bond, 2011).

iii.) PH Measurements

For optimum performance, microorganism in the digester require a pH measure of 6.5 to 8 in order to produce methane. The health of the microorganism is quite crucial in the creation of methane and hence a good environment is required for them to live and prosper (Ghimire, 2009).

3.0. Biogas Digesters

3.1. Designs

There are three basic type of biogas plants which have been undergoing modifications to improve various aspects (Ghimire, 2009). The three basic biogas plants are:

- i.) Floating gas holder biogas plant.
- ii.) Fixed dome biogas plant.
- iii.) Fixed dome with expansion chamber biogas plant.

3.1.1. Floating gas holder biogas plant

This design is generally made up of a digester built underground using brick masonry and has an inlet and outlet. The top of the digester is covered using a floating steel gas holder that is commonly used in collecting the generated gas (Karekezi, and Kithyoma, 2007). The floating steel gasholder which is commonly fabricated using mild steel tends to account for more than 40% of the entire plants' cost. Through the floating gasholder, the pressure in the digester is retained at a constant (Ghimire, 2009).

3.1.2. Fixed dome biogas plant

In this design, the digester upper part acts as the gas holder, and hence gas generated from the slurry, it occupies the top part of the digester and hence the pressure exerted by the gas pushes the slurry in the digester lower as it continues to build up (Karekezi, and Kithyoma, 2007). Hence the pressure increases in the digester with more gas and as the gas is collected, the pressure reduces and the level of slurry inside the digester rises. Commonly this design is also built below ground level and very suitable for cold regions (Ghimire, 2009). Since steel parts are not required in this construction, the construction cost is reduced significantly and locally available material can be utilized.

3.1.3. Fixed dome with expansion chamber biogas plant

Just like the fixed dome biogas plant, the digester and gas collector are not separated. This digester has a hemispherical top and a curved bottom which are joined together at their .The inlet side does not have a displacement space and hence the used slurry is moved to the outlet displacement chamber (Ghimire, 2009). This design is considered to be cheaper than the other two designs.

3.2. Characteristics of the Digester Designs

The digesters will be compared in terms of the following main features;

- i.) General set up
- ii.) Design of biogas holder
- iii.) Gas pressure

- iv.) Maintenance cost
- v.) Digester lifespan
- vi.) Construction materials requirements and availability
- vii.) Digester installation cost.
- viii.) Unique extra features

3.3. digester operation and maintenance characteristic

For proper management of biogas production and hence optimum performance, a biogas digester should meet mixing capability, easy to service and silt management and control.

i.) Mixing capability.

Due to the design nature of the fixed dome design. Once the slurry is poured into the inlet, the slurry is not disturbed until it overflows at the outlet. This has resulted in the unspent slurry and hence losing a lot of methane gas in the process. It also makes it difficult for methane gas to travel from the bottom of the pit towards the gas holder part in the digester in a situation that there is a lot of slurry in the digester. Constant mixing of the slurry in the digester would improve the methane gas production from the digester (Hivos, 2009). As a solution, the new design will introduce a mixing component inside the digester to ensure that constant mixing is archived and increased the productivity of the digester. Since the design is targeting the rural farm and household setup, we will introduce a mechanical setup for mixing which can be done using hands as opposed to motorized or electrical mixers due to high-cost installation.

ii.) Silting

In most cases, the bottom of the digester we find a very fine and thick silt from the animal dung that builds up with time and reduces the effectiveness, and life span of the fixed dome digester. Removing the silt using the available opening is extremely difficult and reduces the structural integrity of the digester and hence a shorter life span (Hivos, 2009). Introduction of service opening at the top of the digester. This opening will remain shut at all moments when the digester is in operation and will not allow gas to escape. The opening will only be opened once in a long time when the digester is not in operation to remove any silt at the bottom of the digester.

iii.) Serviceability

The internal structural integrity of the fixed dome design needs to be checked from time to time and ensure for any gas leaks. It is also difficult to retrieve foreign objects it without damaging the digester (Hivos, 2009). By creation of an access opening, the digester can be stopped for servicing and when required any time. This will involve the entire process being stopped and repairs made where necessary in the digester and the process continues after the repairs. Based on operation and maintenance requirements of the three biodigester designs most preferable design for a typical rural farm and household would be the fixed dome biogas design. This is due to low maintenance cost and a long life span. (Hivos, 2009). The solutions to the issues raised will form the basic design of our a better

4.0. Electricity Generation From Biogas

Biogas can be used in electricity generation through a biogas run generator. 1m³ of biogas is equivalent to 0.5 to 0.6 liters of diesel or 6kWh. The biogas needs to be de-humified and purified before use in the prime mover (UNESCAP, 2007). Conversion of biogas to electricity involves combusting dry biogas to mechanical energy within a controlled combustion system using a heat engine. The mechanical energy is then used to generate the electrical power from a generator that is coupled to the engine. For small scale biogas to electricity production, combustion engines are a better option because they have higher efficiency and low cost compared turbines of similar capacity (UNESCAP, 2007). The engine can be used in a cogeneration mode where the heat can be recovered from the cooling and exhausted for heating applications. This combined heat and power can increase thermal efficiency of the engine to as high as 90%. In an alternative design, a micro turbine can be operated by burning biogas in a micro cogeneration. Mini cogeneration concept can be used to produce 5kWe to 500 kWe electricity with any excess energy being fed to the electricity grid (UNESCAP, 2007). Figure 2 below is illustrates a biogas with power production capability

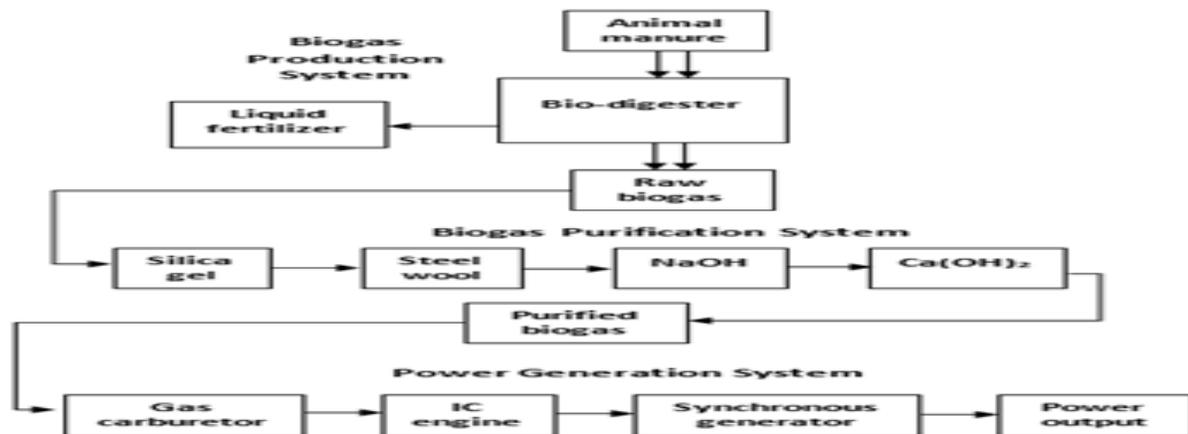


Figure 2: Biogas to electricity process (Energypedia, 2016)

From figure 2, it is noted that to generate electricity from biogas at farm level, the system should be equipped with a prime mover like an internal combustion engine driving a synchronous generator. The synchronous generator ensures constant frequency generation. A carburetor, biogas purification system and the biodigester are other critical elements of the electricity generation system.

4.1. Conversion with Fuel Cells

It is possible to convert biogas directly into electricity by using a fuel cell. The challenge of this route is that the process needs very clean gas and quite expensive fuel cells to be effective. Therefore, generation option is still at research and development stage. (Energypedia, 2016)

4.2. Stirling engines

The Stirling engine concept was developed many years before the introduction of the diesel engine by Rudolf Diesel. The engine is also known as hot-air or hot gas engine (Thombare & Verma, 2008). Stirling engines operate as a closed thermodynamic cycle can operate on multi-fuels hence the potential to reduce fossil fuel consumption compared to the conventional combustion engines. It also offers low noise levels, clean combustion and operational range even with low temperature (Thombare & Verma, 2008; UNESCAP, 2007). The main challenge of Stirling engines is the dynamic behavior of the engine working mechanism and the heat exchanger performance which limit the design affecting reliability and efficiency of the engine. Investigations proposed in the literature attempt to address optimal system design challenges identified (Cheng & Yang, 2012; Thombare & Verma, 2008). The Stirling engine has the potential to be used efficiently in micro-CHP systems driven by solar, biogas, or medium–low grade waste thermal energy (Thombare & Verma, 2008, Kontragool & Wongwises, 2003). Biogas can be used in electricity generation through a biogas run generator. 1m³ of biogas is equivalent to 0.5 to 0.6 liters of diesel of 6kWh. The biogas needs to be de-humidified and purified before being combustion in the engine (UNESCAP, 2007).

Stirling systems generating up to 10 kW of electric power output are currently in the market. They range from 1 to 9 kW capacities with thermal power dispersion of 5kW to 25 kW, which is ideal for household boilers (Barbieri, Spina, Venturini, 2012; UNESCAP, 2007). Their electric efficiencies of Stirling engines range from 13% to 25%, but can be increased with adoption of combined heat and power, the efficiency can reach 80% and greater. Li et al. (2012) developed a small-scale Stirling engine driven by mid-high temperature waste gases, and obtained a maximum power output of about 3.5 kW. These results were in fair agreement with predicted output power of 3.9 kW, with postulated thermal efficiency 26% (Bahaa, Gerald, Martin, & Johann, 2007; Barbieri, Spina, Venturini, 2012). In biogas power generation with Stirling engines, biogas is burnt externally, which in turn heats the Stirling engine through a heat exchanger. The gas in the Stirling motor hence expands and thereby moves the mechanism of the engine. The resulting work is used to generate electricity. The Stirling engines have the advantage of being tolerant of fuel composition and quality but they are relatively expensive and characterized by low efficiency and have limited applications. In most

commercially run biogas power plants today, internal combustion engines have become the standard technology either as gas turbines or diesel engines (Energypedia, 2016). For small scale biogas to electricity production, combustion engines are a better option because they have higher efficiency and low cost compared turbines of similar capacity (UNESCAP, 2007). The engine can be used in a cogeneration mode where the heat can be recovered from the cooling and exhausted for heating applications. This combined heat and power can increase thermal efficiency of the engine to as high as 90%. In an alternative design, a micro turbine can be operated by burning biogas in a micro cogeneration. Mini cogeneration concept can be used to produce 5kWe to 500 kWe electricity with any excess energy being fed to the electricity grid (UNESCAP, 2007). Figure 3 below shows the internal structure of a Stirling engine which can run on biogas and generate power.

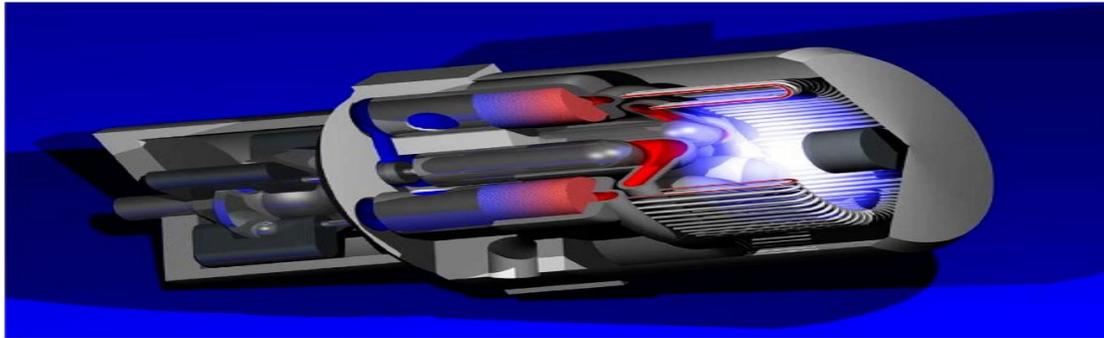


Figure 3: Stirling Engine (UNESCAP, 2007).

Figure 3 is a Stirling engine that can be effectively used to generate electricity by coupling to a generator. The engine is more suitable than conventional engines in power generation and can run on different grades of biogas but are more complex as shown in the figure 3, making them more expensive.

4.3. Diesel engines

Diesel engines can operate on biogas only or in dual fuel mode but to facilitate the ignition of the biogas, a small amount of fuel or fossil oil like diesel is injected together with the biogas. Biogas engines which run dual fuel mode have the advantage of running on fuel with low calorific value. Up to engine sizes of about 200kW the pilot injection engines seem to have advantages against gas motors due to slightly higher efficiency (3-4% higher) and lower investment costs (Energypedia, 2016). Over 4,000 biogas plants with internal combustion engine motors are in operation in Germany. However, it has taken lengthy and determined effort to make this technology as durable and reliable as it is today. Internal combustion engines have high requirements in terms of fuel quality. Components like hydrogen sulphide in biogas can damage the engine and so quality should be controlled. To manage fuel quality, production process should yield clean biogas but where it is possible, use of appropriate and robust components. Theoretically, all engines designed for cars, trucks, and ship can run on biogas as a fuel.

4.4. Petrol Engines

Spark ignition engines or Otto cycle systems, can operate on can be on biogas alone. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets of capacity about 0.5-10 kW as well as for large power plants. In countries like Germany these engines often operate without additional fossil fuels hence lower feed-in tariffs according to the Renewable Energy Law (Energypedia, 2016 UNESCAP, 2007).

4.5. Gas Turbines

Small biogas turbines can be used for power outputs of 30-75 kW and are readily available in the market. However, they are rarely used for small-scale applications in developing countries. They are expensive and due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is a challenging issue from both the engineering and material point of view. Maintenance of such a turbine is very different from well-known maintenance of a truck engine and therefore requires specific skills. (Energypedia, 2016; UNESCAP, 2007).

4.6. Biogas Fuel Quality

For biogas to be suitable of use in an engine for power generation, it must meet the following general requirements: methane percentage should be as high as possible, water and CO₂ composition should be as low as possible for high caloric value while the sulphur content should be as low as possible since it is converted to acids by condensation and combustion. The moisture content can be reduced by condensation in the gas storage or along the gas path while hydrogen sulphide (H₂S) content can be reduced by chemical, biological, or physical techniques (Energypedia, 2016). For quality biogas fuel production, the following measures are recommended during production;

- i.) Ensuring an optimized steady fermentation process with continuous availability of appropriate feedstock is important to produce a gas of homogenous quality for use as fuel for steady power generation.
- ii.) The injection of a small amount of oxygen or air into the headspace of the storage fermenter leads to oxidation of H₂S by microorganisms and hence the elimination of a considerable part of the sulphur from the gaseous phase. This is the most frequently used method for desulphurization. The method is cheap and can eliminate as much as 95% of the sulphur from biogas.
- iii.) External chemical treatment in a filter. Which can be done by use of Iron Hydroxide and activated carbon:
 - a.) Iron-hydroxide: This a reversible process in which the filter can be regenerated by adding oxygen. Adsorption material like iron-rich soils, waste material from steel or aluminum production can be used. $\text{Fe}(\text{OH})_2 + \text{H}_2\text{S} \rightarrow \text{FeS} + 2 \text{H}_2\text{O}$
 - b.) Activated carbon: Carbon filters as a standard components are provided for the system. (Energypedia, 2016)

4.7. Energy Production Potential of Biogas Fuel

Appropriate feedstock for electricity-generating biogas plants is available in adequate quantity in many rural households. By developing both small and medium-size biogas units, it is possible to provide significant contribution to public grids besides meeting own electricity demand as demonstrated by several biogas electricity plants in industrialized countries like Germany. Generation of electricity from biogas can be made and reliable renewable energy source with average calorific value of biogas being about 21-23.5 MJ/m³, 1 m³ of biogas is equivalent to 0.5-0.6 liters of diesel fuel or 6 kWh energy content. However, conversion losses, 1m³ of biogas make it about 1.7 kWh per. Larger biogas plants are more cost-efficient compared to smaller plants, electricity generation from biogas can be achieved even for relatively small applications of 10-100kW (Energypedia, 2016; Li et al., 2012).

4.8. Technical Feasibility of Biogas Power plants

Continuous research and development has ensured that biogas combustion for power generation is today a mature technology. With desulphurization engines can tolerate biogas that have proven their durability in power generation. Technical capacity for planning and constructing reliable biogas power plants is available for all markets and countries. Electricity generation from biogas in Africa is still limited to a few pilot plants, for example in Kenya online a few pilot plants are existing (Energypedia, 2016). The challenges facing developing countries is that most biogas power plant spares and plant equipment are not locally available and so is the technical capacity in operation and maintenance. Therefore for the construction of efficient and reliable biogas power plants, at least some technical core components must be imported from industrialized countries. The main advantage is that electricity generation component and process for biogas power plants need sophisticated knowledge and effort for maintenance than a conventional generator for fossil fuels with a well-functioning biogas fermentation process as an indispensable prerequisite (Energypedia, 2016; Amigun, 2008).

4.9. Economic Feasibility of Biogas Power Generation

Traditional grid power faces challenges like rising fossil fuel prices and low reliability of power supply with persistent risk of power cuts and vulnerability of supply from hydro power to drought and intermittent supply from wind and solar and long gestation periods and huge capital requirements for geothermal energy (Kabeyi, 2020).

4.9.1. Conditions for economic viability

The economic feasibility or viability of biogas plants for industrial and domestic applications is dependent on opportunities for product and utility diversification. It makes economic sense if biogas installations have can be used to supply all or many of the following extra applications;

- i.) Electricity or mechanical power applications for local and export supply to the grid
- ii.) Biogas as a fuel for other domestic and industrial applications
- iii.) Heat, co-generated by the combustion engine to increase cycle efficiency.
- iv.) The sanitation effect with COD and BOD chemical and biological oxygen demand reduction in the runoff of agro-industrial settings for safe application and disposal of digester effluent.
- v.) Application of the slurry in agriculture as farm fertilizer or manure.

A combination of the above applications will make biogas electricity generation to be technically, socially and environmentally sustainable and therefore acceptable to all (Energypedia, 2016; Kabeyi, 2019). Practical assessments of economic feasibility of biogas power generation is contradictory or inconsistent. Many studies give payback periods of only 1.5 – 2.5 years. In such cases, the electricity from biogas plants can be compared to the price of electricity provided through the national grid or the price of bottled LPG. However this sounds unrealistic, except for direct thermal energy used in heating and cooking or in cases where diesel fuel is used directly for power generation or other energy applications (Energypedia, 2016; Jeremiah, 2018). A study in Kenya based on a 50 kW plus plant provided more realistic economic analysis of biogas power generation. In this case, German GTZ experts in Kenya for medium and large plants (>50kW) anticipate payback periods for plants under the DBFZ tariff scheme based on price of 0.15 US\$/kWh) is about 6 years under very favorable conditions, and about 9 years for unfavorable conditions. Unfortunately, recent studies from Africa indicate that electricity generation from biogas has not shown promise of being profitable just because all plants studied were installed with international technical and financial support hence casting doubt over viability of biogas power generation in developing countries (Energypedia, 2016).

4.10. Challenges of Biogas to Electricity Generation

The main barriers to development of the biogas sector in electricity generation are

- i.) Low feed in tariffs
- ii.) Capacity of grids to absorb small holder generation
- iii.) Lack of awareness of biogas opportunities
- iv.) High upfront costs for potential assessments and feasibility studies
- v.) Lack of access to finance
- vi.) Lack of local capacity for project design, construction, operation and maintenance
- vii.) Legal framework conditions that complicate alternative energy production and commercialization: for example, the right to sell electricity at local level has to be in place.

As long as the national framework conditions are not favorable, electricity generation from biogas will remain limited to a few pilot applications.

5. BIOGAS FOR HEATING APPLICATION

To use biogas for heating e.g. Cooking, or lighting, the main objective will involve drying the gas and also separating it from other unwanted gases like hydrogen sulfide. For a common household, the best way will involve piping the gas and passing it through silica gel to dry it (Moses, 2018). The piped gas can be directly tapped into the house and

direct to the burner/stove where it is used. Excess gas can be stored and used later through the use of nonporous strong polythene bags. Figure 4 shows the biogas cooking system.

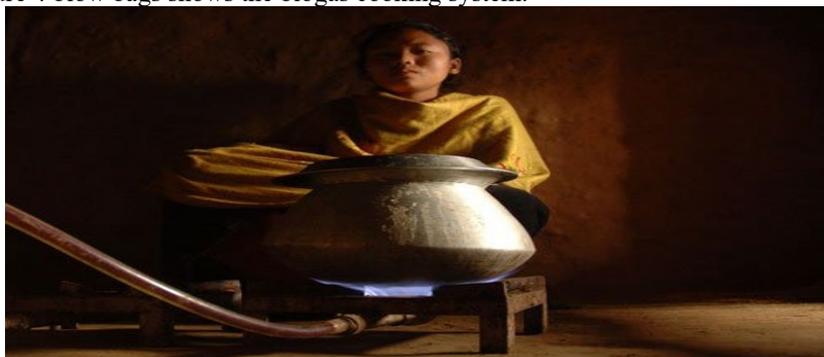


Figure 4: Woman cooking using biogas

From figure 4, it is noted that for biogas to be used in heating or cooking, burner, gas piping and gas cooker are necessary. With a burner, it is possible to use biogas for both heating and lighting. However special biogas lamps are available.

6. BIOGAS FOR FERTILIZER RECOVERY

The use of biogas digester slurry is considered to be a good practice by agronomists, because biogas slurry is 25% more effective in the farm as compared to adding manure directly to the farm. Hence increased productivity is gained using biogas slurry. The slurry can be applied to the farm directly and also used as foliar fertilizer by mixing it with water and applying it to the required leaves. The slurry is collected through a ditch which is fed as the digester is recharged (UNESCAP, 2007; Li et al., 2012).



Figure 5: Woman using Used slurry in farming

Figure 5 shows a method of slurry application in the agricultural field, where the bio-digest is applied to the soil. Use of the slurry as fertilizer improves agricultural productivity and helps sustain biogas production and use.

7. Biogas yield from different Agricultural wastes

i.) Dung

If the daily amount of available dung (fresh weight) is known, gas production per day in warm tropical countries will approximately correspond to the following values:

- i.) 1 kg cattle dung 40 liters biogas
- ii.) 1 kg buffalo dung 30 liter biogas
- iii.) 1 kg pig dung 60 liter biogas
- iv.) 1 kg chicken droppings 70 liter biogas

ii.) Biogas potential of farm animal and humans

Different farm animal dung yield differing quantity biogas which can be estimated based on the live weight of the animals. The daily gas daily gas production can be estimated as follows;

- i.) Cattle, buffalo and chicken: 1.5 liters of biogas per day per 1 kg live weight
- ii.) Pigs, humans: 30 liters biogas per day per 1 kg weight (Energypedia, 2016).
- iii.) Each kilogram of biodegradable material yields 0.4 m³ (400 liters) of gas.
- iv.) Gas lights consume around 0.1m³(100 liters) of gas in one hour (Energypedia, 2016).

Table 1 below shows gas yields and methane contents for various substrates at the end of a 10-20 day retention time at a process temperature of roughly 30°C. (Energypedia, 2016).

Table 1: Gas yield and methane content for different biomass (Energypedia, 2016).

SUBSTRATE	GAS YIELD (L/KG VS*)	METHANE CONTENT (%)
Pig manure	340-550	65-70
Cow manure	90-310	65
Poultry droppings	310-620	60
Sheep manure	90-310	
Wheat straw	200-300	50-60
Rye straw	200-300	59
Barley straw	250-300	59
Oats straw	290-310	59
Corn straw	380-460	59
Flax	360	59
Hemp	360	59
Grass	280-550	70
Elephant grass	430-560	60
Vegetables residue	330-360	
Sunflower leaves	300	59

Agricultural waste	310-430	60-70
Seeds	620	
Peanut shells	365	
Fallen leaves	210-290	58
Sewage sludge	310-740	

From table 1, it can be deduced that different types of biomass has different biogas quality and quantity yield. To quality biogas in terms of methane content can be got from algae, pig manure, agricultural solid wastes, and grass among others. In terms of quantity of gas, highest yield can be gotten from algae, sewage sludge, sugar beet, clover, elephant grass and corn straw. This means that a farmer can maximize biogas production by selecting high biogas yielding farm material for his digester while ensuring sustainable agriculture from his/her farm (Li et al., 2012).

7.0. Design Analysis

A simple analysis will show that a small household will require a generator of average capacity of 1200W to ensure proper electricity production for all needs. However different households may have different electricity needs as well as varying demand patterns which affect the peak demand. The total daily energy requirement for electrical purposes can be taken as 1.6kWh, hence with an average continuous running time of 6 hours totals to 9.6kWh. It is also noted that 1m³ of biogas is equivalent to 0.5 to 0.6 liters of diesel of 6kWh. Biogas has an average calorific value of 21-23MJ/m³ (Karekezi, and Kithyoma, 2007). This means that 1m³ of biogas is the same as 0.5-0.6 liters of diesel of 6kWh. With the average required heating energy being 8.2kWh, these requires about 1.4m³ of biogas each day to cater for the heating requirements. Therefore, the total biogas needed per day to cater for both electrical and heating requirements is 14m³ of biogas. Other considerations are;

- i.) Gas production per day per animal in rural farms are as follows.
- ii.) 1kg of fresh cattle dung produces 40 liters of biogas
- iii.) 1kg of fresh pig dung produces 60 liters of biogas
- iv.) 1 kg of fresh chicken droppings will produce 70 liters of biogas

A healthy cow produces about 14 to 16kg of cattle dung every single day. This amount plus 0.06 liters of diesel can used to run the generator and produce 1kWh of electricity (Karekezi, and Kithyoma, 2007). Hence, we will require 4 cows to run our 10m³ biogas plant and a 1200W biogas generator. According to Karanja and Kiruiro (2003), for a typical rural farm establishment, operation and maintenance costs can be minimized since main activity is feeding the digester with fresh slurry, which typically takes less than 30 minutes and with this, it is possible to incorporate this activity the day to day running of the dairy farm and avoid extra labor.

7.2 Energy Calculation of the Biogas

The Average cost of electricity in kWh is \$0.15 shillings in Kenya, but may vary from one country to another and hence a rural household using 9.6 kWh daily will be required to foot a bill of \$ 1.44 per day which can all be catered for by the biogas digester and hence have a significant saving. Also, the heating requirements which are mainly catered through the burning of wood, and wood can be substituted by the biogas. Heating cost on a daily basis is averaged to around US\$ 1.0. This means that an effective biogas plant can have a daily saving of US \$ 2.44 towards the energy need of the rural household. The saved income can be utilized in other development activities by the rural household and improve their standard of living.

7.3 Socioeconomic Impact of the Biogas Design

By using a bio-digester, a rural farm household is able to utilize the available resources in the farm and make some significant financial saving to a tune of \$ 73.20 and live comfortable and healthy live. The overall effect is improved the food. Using biogas will also reduce the overdependence on grid electricity and petroleum products, and hence energy security. With the increased adoption of alternative sources of energy, countries will reduce imported

petroleum products which saves the foreign reserves and mitigates against greenhouse gas emissions and global warming.

8. Conclusion

This study recommends a multipurpose approach in the design of farm based biogas systems that will address the electricity needs, heating requirements, land fertility and waste management at farm level. A Stirling engine is proposed although there are several other gas to electricity conversion systems which include fuel cells, micro turbines, diesel engines, Otto cycle or petrol engines or the gasification technology with gas turbine. Redesign for improvement on available digester designs is recommended for adequate operation and maintenance at farm level especially for smallholder farmers. The normal electrical wiring will be required in the farm and all connected to the generator and/or chemical battery for electrical use while allowing for grid connection to facilitate both import and export of electricity from the biogas system. Since the generator will not be running at all time, when the gas produced is in excess, the farmer will seek to generate electricity and store it for later use. Biogas can be used for electricity generation at household level or grid supply, direct heat application or bio-methanation to enrich and package in containers for sale mainly for domestic and industrial heat application. A Stirling engine is ideal for small scale domestic electricity generation from biogas. However other feasible options are the gas turbine, fuel cells, diesel engine, Otto cycle engine or petrol engine.

To avoid wastage of excess biogas, the excess will be used to generate electricity for storage or supply to the grid. Biogas is effective and efficient as cooking gas with little environmental problems which can be managed like methane leakage and risk of fire from leakages exposed to any form of naked flame. Through the costing, the biogas plant has proved to be very cost efficient and remarkable source of alternative energy. The amount of raw material needed for a continuous biogas digester process has been identified as a minimum of 4 cows producing an average of 14kg of fresh dung daily to produce the required biogas for the rural household. Cows were used for the design parameters as they are the most common animals in every rural household. However other animals like pigs and chicken are feasible alternatives. Biogas production can be improved through better digester design with the stirrer being introduced to make it easier to mix the slurry in the digester and hence get the most out of the prepared slurry. Also, the design incorporates a top trap door to enable easy servicing of the digester from time to time and avoid silt deposit at the bottom of the digester.

The economic feasibility or viability of biogas plants for industrial and domestic applications is dependent on opportunities for product and utility diversification. It makes economic sense if biogas installations have can be used to supply applications like electricity or mechanical power applications for local and export supply to the grid, biogas as a fuel for other domestic and industrial applications, heat, co-generated by the combustion engine to increase cycle efficiency. The sanitation effect with COD and BOD (chemical and biological oxygen demand) reduction in the runoff from agro-industrial has a significant positive impact on environmental management and pollution control by agro based establishments. Application of the slurry in agriculture as farm fertilizer or manure will improve farm productivity and revenue for farmers. The multiple application of biogas and attractive feed in tariffs will make it possible for stallholder farmers to invest in export based electricity generation from biogas and make agriculture more sustainable and profitable.

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