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RESEARCH ARTICLE

EVALUATION OF BIOGAS PRODUCTION AND SLURRY FROM ORGANIC SOLID WASTES FOR AGRICULTURAL PRODUCTIVITY AND RURAL DEVELOPMENT

Emmanuel Amankwah[1] and Hamidatu S. Darimani[2]

Department of Agricultural Engineering, Wa Polytechnic, Box 553, Wa

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**Corresponding author:*
trustee7a@yahoo.com

ABSTRACT

This research is to evaluate biogas production and slurry using organic solid wastes for agricultural and rural development. Solid wastes management have been a major challenge for Metropolitan, Municipal and District Assemblies (MMDAs) as the organizations responsible for managing wastes in their communities. The major challenges identified are the lack of separation of wastes, low technological know-how, inadequate landfills and lack of basic infrastructure for managing the wastes. The research involved a visit to various regional and district capitals to observe waste management challenges; a thorough review of literature on solid wastes and biogas technology. It was observed that about forty percent of solid wastes are not collected and heaps of wastes have become common in some of the cities. The research also revealed that the solid wastes are mostly collected and disposed without treatment and such wastes contain over fifty percent organic matter. It was also discovered that so much money is spent on wastes management alone which has a toll on the MMDAs especially AMA. The research indicated the process involved in the conversion of organic solid wastes component into energy and slurry for agricultural productivity and rural development. The research outlines the energy content of organic solid waste, composition and application of the biogas and the digested slurry. It further stated the measures to ensure sustainable biogas project and concluded with suggested recommendations.

INTRODUCTION

Many African countries including Ghana face various challenges from poor waste management and sanitation of an ever increasing population. United Nation Environmental Programme (UNEP, 2002) report indicates that solid wastes disposal is a major concern for African nations due to population explosion, poverty and high urbanization rate coupled with ineffective and low funding by governments for efficient waste management. Consequently, waste management authorities face difficulties managing waste generated in most cities and towns. Accra Metropolitan Assembly (AMA) estimated that the city of Accra alone generates between 1500-1800 tonnes of waste every day but on the average, only 1200 tonnes of waste is collected for disposal daily leaving about 40% of waste uncollected and the situation is not different from high population density areas. Pace Moody (2003) has argued that if capacity for waste management is not drastically increased, potentially 72% of the population will not be served by the existing waste management services. Due to scarcity of landfills, wastes collectors have to travel 25-100 km to dispose of wastes. The situation is even aggravated by weak institutional capacity, lack of basic facilities and resources, both human and capital. This affects the regular collection of wastes resulting in heaps of uncollected wastes causing nuisance and health hazards to the general public. The Accra Metropolitan Assembly (AMA) is said to spend GH¢ 1,000,000 monthly on solid waste management which is about 65-70% of their revenue. (Daily Graphic, Wed. Oct. 13, 2010). In the Upper West Region, the Wa Municipal Assembly spends about GH¢114,000 monthly to deal with waste management; about 75% of such money only goes into wastes collection and transportation (Wa Municipal Assembly, 2009).

Literature Review

It is also estimated that only 30% of the wastes generated are collected and disposed. Such collection is even limited to mainly high and middle income areas while the low-income areas are left to contend with the problem on their own. This situation has led to indiscriminate disposal of waste into surface drains, canals and streams; creating unsanitary and unsightly environments in many parts of the city. The recent cholera outbreak due to poor sanitation recorded about 6,000 cases with over 70 deaths. According to WHO, 900 million people experience diarrhea or contact diseases such as typhoid and cholera through contaminated water (WHO, 2008). According to the United Nations Conference on Human Settlement (UNCHS, 1996) report, one-third to one-half of solid waste generated within most cities in low and middle income countries such as Ghana are not collected. Fortunately, research has shown that about 50-70% of the wastes generated are bio-degradable which makes it possible to convert such waste into energy with the byproduct capable of improving crop production. Tsiboe and Marbell (2004) also reported that organic matter makes up 65% of municipal waste, inert materials 17.1% of the weight with paper taking 6%, plastic is 3.5%, glass 3%, metals 2.5%, textiles 1.7% and 1.2% making up the rest. Solid wastes in developing countries are composed of over 50% organic materials (Hoornweg et al., 1999). Zhang (2007) also stated that food waste including uneaten food and food preparation remains from various establishments is considered the largest component of waste stream by weight. Waste in Ghana is commingle and mainly putrescible thus the need to separate such waste to allow further treatment and recycling. UNESCO (2003) argued that developing nations could hardly manage solid wastes due to factors such as waste composition, technologies and lack of infrastructure for managing the waste. With technological advancement and research, wastes should no longer be an environmental issue but a resource for energy production as many countries have successfully converted organic waste into biogas energy and bio-fertilizer. The conversion of organic material into biogas and fertilizer would help reduce the importation and application of chemical fertilizers, improve crop yields, and help address other environmental challenges. According to the Bio-energy Insight, Huishan Dairy in China with about 250,000 cows has installed a methane capturing devise which could generate about 5.6 MW from 60,000 cows. It could also generate 619,770 tonnes of fertilizer and reduce carbon emissions by 180,000 tonnes per year. From this background, there is the need to evaluate the production of biogas energy and fertilizer from organic waste so us to turn the wastes into wealth.

Synopsis of Anaerobic Digestion of organic solid waste

An anaerobic digestion is one of the ways to convert wastes into wealth. The process of anaerobic degradation of organic material is both biologically and chemically complicated with many possible intermediate of reactions. The micro-organisms involved in the production of biogas from organic waste are bacteria. There are three main bacteria namely aerobic bacteria, facultative anaerobic bacteria and the anaerobic bacteria, which are responsible for the production of the biogas. The aerobic bacteria are those, which grow in the presence of oxygen. The facultative anaerobic bacteria are those which can metabolize and grow with or without oxygen while the latter grows only in the absence of oxygen (Hobson et al, 1981). The whole process is divided into three stages namely Hydrolysis, acid and methane producing stages (GTZ-GATE, 1999)

Hydrolysis or Liquidation Stage

The constituents of organic waste materials in the feed stock are mainly carbohydrates, lipids, proteins and inorganic which are broken down by bacteria. The feed stock contains complex molecules and long-chain fatty acids. The long-chain fatty acids can be in saturated or unsaturated forms (Heulelekian and Mueller, 1958). Irrespective of the number of long chain acids present, the mechanism for degradation is always similar. This involves the breakdown of complex long chains organic molecules into simpler shorter molecules by the action of extra cellular enzymes. For instance, starch and glycogen, which are carbohydrates, are hydrolyzed to a disaccharide by the action of amylase – one of the enzymes. Lipases and esterases hydrolyze fats and lipids (oil). The enzymes are also known to be specific in their reaction. The enzyme trypsin is specific for bonds involving the amino acids (Fruton and Simmonds, 1959). Also exopeptidases are limited to terminal peptide bonds but endopeptidases must attack peptide bonds that are centrally located in the peptide chains. The enzymes are also responsible for the conversion of proteins into peptides and amino acids; polysaccharides to monosaccharides.

Acid Formation Stage

This stage involves the transformation of the fermented intermediate materials into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide (CO_2) by acidic forming bacteria. The bacteria (acidogenic and acetogenic) use up all the oxygen present creating an anaerobic environment for the methane-producing micro-organisms to react afterwards. They also reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen, sulphide and traces of methane. The removal of the oxygen is characterized by extremely small changes in energy per unit substrate decomposed (McCarty, 1971).

Methane Formation

The final stage of the process is the methane producing stage, which involves methane-producing bacteria called methanogenic bacteria. Methane forming bacteria are sensitive to pH and the conditions should be mildly acidic (pH 6.6-7.0) and certainly not below pH 6.2 (Twidell and Weir, 1986). These bacteria convert the compounds formed during the second stage into a low molecular weight such as methane and carbon dioxide in the absence of oxygen. Both acidogenic and acetogenic bacteria and the methanogenic bacteria act in support of each other in that the anaerobic condition created could be poisonous to those bacteria if not used up by other bacteria while the methanogenic bacteria could not also operate without such an environment.

Characteristics of biogas

The gas produced is pressure and temperature dependants and also affected by traces of water vapour. The presence of water vapour could affect its application in engines thus it is appropriate to treat the biogas by cooling. The biogas pipe is routed underground to condense the water vapour at lower temperature then warms to reduce the moisture content of the gas (Werner et al., 1989). Yadav and Hesse, 1981 researched into the composition of biogas and came out with the following: Methane (50-70%); Carbon Dioxide (30-40%); Hydrogen (5-10%); Nitrogen (1-2%); Water vapour (0.3%) and Hydrogen Sulphide (traces). Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650° to 750°C with calorific value of 20 MJ/m^3. The gas is odourless and colourless; burns with clear blue flame similar to natural gas with 60 percent efficiency in a conventional biogas stove (Sathianathan, 1975). According to Pokharel & Yadav, 1991 biogas has a heat value of $6kWh/m^3$while natural gas has $11kWh/m^3$. It is also a clean and odourless combustible gas (like natural gas) which is produced when biodegradable matter are anaerobically fermented or digested by methanogenic bacteria.

MATERIALS AND METHODS

The research involved a visit to various regional and district capitals to observe waste management challenges. Some of the places visited are the Wa Municipality, Techiman Municipality, Kumasi and Accra Metropolis. The targeted areas were around market centres where mainly organic wastes are generated. A thorough review of literature on solid wastes and biogas technology was also carried out to evaluate the possibility of using the organic portion of the wastes to generate biogas and the byproduct used as fertilizer for crop production.

RESULTS AND DISCUSSIONS

From the field visits, it was observed that most of the wastes generated around the market centres contain rotten food stuffs and debris. A lot of black polythene bags were also observed in the wastes. There were heaps of uncollected wastes in containers and on the ground around the public toilets behind the lorry station especially in Techiman. One observation in Esreso along the route to Adagya was very pathetic. A large heap of wastes had almost taken over the road. Unfortunately, the place is a low land and is most likely that the leachate from the wastes will affect the wells dotted around the area. The story is similar in other places in Kumasi and Accra. There is therefore the need for city authorities to take a closer look at such scenarios to avert any possible outbreak of cholera and other environmental related diseases. From the extensive literature reviewed, it was observed that organic wastes are made up of over 50% biodegradable materials. Tsiboe & Marbell (2004) reported that organic matter makes up 65% of municipal wastes. Wastes generated also contain about 50% organic component (Hoornweg *et al*. 1999). A research conducted in Accra in 2005 also estimated that waste generated contains about 50-70% biodegradable materials and Zhang (2007) also concluded in his research that food wastes including uneaten food and food preparation remain the largest component of the waste stream. From the above figures by the researchers, it could be concluded that over half of the wastes generated could be diverted from landfills and purposely used for wealth generation. Kaltwasser, 1980 cited by Werner *et al*., 1989 also revealed the energy content of organic wastes which consist of carbohydrates, organic fats and proteins and this further confirm the possibility of using organic wastes to generate energy for rural development (Table 1).

Already there are some companies in Ghana which have started recycling plastic wastes and if a few companies also come on board, the issue of plastic wastes could effectively be addressed. Tema Steel Company has been very efficient in recycling metal wastes thus clearing all forms of metal wastes in the wastes stream. Most of the beverages companies such as coca cola, Kumasi brewery and many others also take back their bottles for reuse thus the amount of bottle wastes is very minimal is the wastes stream. The only major challenge is to address the organic component of wastes which forms the bulk of the wastes component.

It was also revealed by the AMA chief executive that about GH¢1,000, 000 is spent monthly on waste management in Accra with a population of about four million. The Wa Municipality has a population of about 750,000 also spends about GH¢144,000 and the situation could be similar to other regions. This basically implies that so much money is spent on wastes management and part of this money could be used to establish biogas plants to digest organic wastes to produce energy and slurry. If this is done, less waste will be left to be dumped and the urgent need for landfills will be drastically reduced.

Pretreatment of solid wastes

Since wastes generated in Ghana is commingle, the organic wastes component must first be sorted out at source and separated from other forms of waste for pretreatment before introduced into the digester. To ensure effective wastes separation, the system must be supported by a legislative instrument to compel people to separate their wastes. Separation of the wastes will facilitate recycling and energy recovery. To ensure quick degradation and high yield of biogas, pre-treatment of the organic wastes is very important. According to Delgenès *et al.* 2003, organic waste can be pretreated biologically, mechanically and chemically. For this study, mechanical method of pretreatment would be considered. The mechanical means of pretreatment is aimed at reducing the particle size and increase the surface areas to enhance the activities of the microorganisms. With this, materials such as sewage sludge, animal manure and abattoir wastes can be co-digested with the pretreated organic waste component for biogas production (Hartmann & Ahring, 2005).

Population growth and wastes generation

Population growth and waste generation are interrelated. The higher the population, the more likely waste production will increase. This situation therefore requires proper management to deal with the abundant wastes produced and one of the ways to efficiently deal with the wastes is to convert the biodegradable component of the wastes into energy thus saving the difficulty of securing landfills for waste disposal. Salhofer et al, 2007 estimated 2-3% annual rise of solid waste. The national population growth rate in Ghana is estimated as 2.7% while that of the urban is 4.6% (GSS, 2002). Already the country is burdened with how to effectively manage the wastes systems and this call for the need to identify various options to adequately manage our wastes stream. Anaerobic digestion of organic solid wastes will be one of the best alternatives to address the menace of waste management in the country because of its economic benefit. The energy generated and the slurry could be used to compensate the cost of waste management. Nayono *et al.* (2010) also reported in his thesis that anaerobic digestion is a well-known and reliable technology to treat and convert organic solid wastes to methane for energy production as part of municipal policies for the reduction of green house gas emissions. This therefore implies that organic wastes are very valuable resource to be used to transform the lives of rural communities. According to Ji Ji Qin & Nyns (1993), municipal wastes treatment through anaerobic digestion process is more beneficial than other methods such as landfill, incineration and others.

Community biogas plant and energy production

Biogas can be produced from simple raw materials such as animal dung, food wastes, agricultural residues, municipal waste materials and waste from abattoir. It can be used for electricity and heat generation when fed into a biogas generator, pressurized for use in public transport and as a fuel for cooking in homes - a substitute for natural gas. It is established Hobson *et al* (1981) that biogas has the same characteristics as natural gas and is interchangeable. Biogas plays a key role especially in communities very far from the national grid which have not even dreamt of being connected to the national grid. Besides, it also saves the environment from degradation especially deforestation. Majority of people leaving both in urban and rural cities rely on charcoal and fuel wood for cooking thus the use of biogas could save our forest from further depletion. Trossero (2002) argued that about 90% of wood fuel is directly from natural forest and about 60% are used for energy purposes. While the advanced countries use only 30% of wood fuel for their energy purposes, less developed countries use as much as 80% for the same purposes. Even with the use of firewood, women and children have to travel long distances and spend most of their time collecting fire wood. Despite the precious time spent collecting fire wood; their activities also cause irreparable damage to the forest and the ecosystem and affect the education of most of their children. A research conducted by Britt (1994) indicated that two-third (2/3) of women and children spend about six hours a day collecting fire wood. Despite the damage caused to the environment, the exposure to smoke of the women using fire wood cause serious coronary and respiratory diseases (Hurst and Bamett, 1990).

The use of biogas for cooking therefore will save women from the health hazards associated with firewood and charcoal. It is for this reason that the research seeks to evaluate the production of biogas energy and fertilizer application using animal and other organic wastes. It was estimated that about 6 million small scale biogas digesters were installed in 53 developing countries between 1973 and 1987 (FAO, 1996). China and India have really made an unprecedented development of biogas implementation. Sichuan Provincial Biogas Development Office, 1979 cited by UNEP, 1981. In china there are about 400 biogas power stations with a total capacity of 7,800 kW which provides electricity to 17,000 households (FAO, 1996). Biogas could be used to generate electricity for farming and rural communities. The use of biogas in biogas generators to generate electricity for community lighting is a better option than for direct lighting. ETSU (1994) also confirms the use of biogas in gas engine to generate electricity as one of the options for biogas application. The use of organic component of municipal wastes through anaerobic digestion is very appropriate for small clustered communities. The energy produced from the organic waste can be fed into generators and supply to small farming communities without light to improve upon their living standards. The use of organic waste to generate electricity and biogas for cooking will therefore help families in the farming communities to live decent lives. Antoni & Schwarz (2007) confirms that the end product of biogas is used for stationary power generation or be compressed after purification and enrichment and then fed into the gas grid or used as fuel in combustion engines or cars.

Digested slurry from biodegradable waste

The use of digested slurry for soil improvement and crop production is much preferred as studies in China on the survival of pathogens has proved that about 90 to 95 percent of parasitic eggs are destroyed at the mesophilic temperature while at times ascaris are reduced by 30 to 40 percent (UNEP, 1981). The biogas slurry is used extensively in agriculture, aquaculture and for raising earthworms, and growing edible fungi. Applications of manure have resulted into higher crop yields compared to the use of chemical fertilizer alone (Hurst & Baraett, 1990). Research conducted by Pantastico (1976) revealed that organic matter will have six to eight times more nutrients than they derive from chemical fertilizers. The digested slurry also contains excellent nutrients such as N, P, K, Ca, Mg, Fe, S and other trace elements Ames (1976). The gas and the digested slurry generated could be sold at affordable prices for farmers and the proceeds used to service the plant and pay workers. One of the challenges that may arise here is the ability to pay as most people in the rural areas can hardly pay for the services. As part of government responsibility to meet the need of the poorest of the poor, special subsidy could be given to such people. The digested slurry could also benefit farmers who practice eco-farming as this had improved crop production and enhanced the lives of such farmers tremendously (Amankwah, 2011).

Sustainability of biogas project

Community biogas project is likely to face neglect and low patronage if the necessary precautions are not taken into consideration during implementation. Despite the numerous advantages such facility will bring to the community, the project could face opposition from the local people. It is therefore very important to address all socio-cultural and economic implication of the project before its implementation. The following should be considered:

- Participation of the community especially women in all decision making process of the project
- Community and organizational leaders should be involved in the coordination of the project to establish openness, accountability and trustworthiness between the community and the implementing agency.
- The location of the biogas plant should be clean and aesthetic to make it socially acceptable.
- If the gas will be used for cooking then modern gas burners which are durable and inexpensive should be provided.
- The organic material should be available, sorted and treated for the digester
- There should be reliable energy supply if the biogas is to be used for electricity supply or for cooking.

Conclusion and Recommendations

It is very clear how organic matter of wastes could be used to generate biogas and fertilizer instead landfill. As developed countries convert wastes into wealth, developing countries can also take a queue from the developed countries. The use of

Table 1: Energy potential of organic compounds

Material	biogas (l/kg)	CH_4 Vol. %	CO_2 Vol. %	Energy Content (Wh/g)
Carbohydrates	790	50	50	3.78
Organic fats	1270	68	32	8.58
Protein	704	71	29	4.96

Source: Kaltwasser, 1980 cited by Werner *et al*., 1989

organic wastes into energy will improve sanitation and the general environment. Even though the initial capital for establishing community biogas plant could be very expensive but if the government is indeed interested in arresting the environmental challenges such as deforestation, poor sanitation and the general health of its citizenry, then it will not be out of place for the government to install biogas plant to provide energy and fertilizer to farming and rural communities. Even though the use of organic wastes seems to be very profitable, cost benefit analysis should be carried out before private individuals invest in such venture.

It is therefore recommended that

1. Separation of wastes at source at all levels of production is supported by a legislative instrument
2. Recycling of solid wastes especially organic wastes should be incorporated into wastes management policy
3. Government should provide infrastructure for wastes management in the country
4. Education to sensitize people's perceptions towards sanitation and wastes management should be encouraged and promoted.
5. By-laws and regulations governing waste management must be enforced

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