Fuel Biotechnology: A Strategy for Sustainable Energy Production for Developing Nations

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ABSTRACT

The rapidly dwindling reserves of fossil fuels in recent years have stimulated a great interest in exploring alternative sources of renewable energy such as biogas. Biotechnology plays an important role in the production of biomethane from biological raw materials via anaerobic digestion technology. The development in biotechnology and engineering sciences in the last a couple of decades has provided many new possibilities to improve the performance of the technology .This study focused on the prospect of biomethane as a sustainable energy production for developing nations using Nigeria as a case study. An underground biodigester made of concrete was designed and constructed for a household in Ibadan .The digester was dug to a depth of 1.22m. The floor was made up of gravel, sand and cement. The digester was initially filled with 3300 litres of water. Cattle dung and water hyacinth were mixed with 1,100 litres of water to form slurry. A pH meter was used to measure the pH of the slurry. The slurry was used to charge the digester. The digester was subjected to anaerobic digestion for seven days after which the pressure rose indicating gas production in the digester. The biogas produced was stored in the digester. The gas was scrubbed to remove impurities, measured and monitored by using artisanal manometer. The digester produced biogas. The gas produced was flammable, odourless and smokeless. The gas generated was enough for domestic activities such as cooking a variety of staple foods by a household of six people. The household used an average of $0.30m^3$ of biogas per hour. The household preferred biomethane to other conventional ways of generating fuel since they could get the feedstock easily from a nearby farm thereby saving cost of buying fuel. Advancement in biotechnology is set to change our world. Biomethane technology using anaerobic digestion will play a vital role. The developing nations such as Nigeria which depends solely on fossil fuels needs a paradigm shift from conventional sources of generating fuel such as petroleum to unconventional ones that are renewable such as biomethane.

Keywords: Anaerobic digestion, Biomethane, Biotechnology, Cattle dung, Digester.

INTRODUCTION

There are to date more than 3.5 billion people, mostly in developing countries, who still rely on coal and biomass—such as wood, dung, and crop residues—as their main source of energy for both cooking and heating. This traditional sources of energy burned in simple stoves with no proper ventilation can be extremely polluting and cause serious environmental health problems (Smith, 2006). Women and children are at greater risk because of household responsibilities and increased exposure indoors (Dasgupta *et al.*, 2004).Furthermore, the rapidly dwindling reserves of fossil fuels in recent years have stimulated a great interest in exploring alternative sources of renewable energy. One of the best-established technologies available is Biogas Technology, where organic materials, e.g. animal manure, night soil, agricultural residues and industrial effluents, are biologically fermented in the absence of oxygen to produce flammable gas consisting predominantly of methane and carbon dioxide. The use of cleaner fuels such as biogas or other modern biofuels can eliminate the current indoor and outdoor air pollution epidemic. Biogas technology not only provides pollution prevention, but also allows for sustainable energy, compost and nutrient recovery. Improving access to modern energy services – including electricity and modern cooking fuels and appliances – is essential if the world is to achieve the Millennium Development Goals (MDGs).The United Nations Millennium Project recommends an additional MDG "target to halve by 2015, the number of people without effective access to modern cooking fuels, and to make improved cooking stoves widely available".

Fuel biotechnology constituted production of energy-dense and convenient-to-use fuels like methane, ethanol, butanol, biodiesel and hydrogen from relatively diffuse and inconvenient-to-use source of energy-e.g. biomass and sunlight through the action of biological agents. Biologically produced fuels are called biofuels and often the names biomethane, bioethanol, biofuels, biodiesel and biohydrogen are used.

Technological progress - particularly in biotechnology - can and will help the energy needs of growing populations in the developing nations. Biotechnology is already helping to increase production of both food and biofuel. It is doing so by boosting agricultural yields and by increasing the efficiency of biofuel production from all feedstocks. Biotechnology also enables production of fuel from non-food feedstocks - switch grass, agricultural residues or trees - which are abundantly available in the developing world.

Biogas was aimed as a substitute for the non-renewable fossil fuels like petroleum, which are declining at an alarming rate. However, the ultimate source of energy for biomethane and fossil fuels is the sun via biomass. Biomass is the total cellular dry weight or organic material produced by an organism (usually from CO_2 and sunlight). In general, biofuels are aimed for use in transport as a substitute for the nonrenewable and rapidly declining fossil fuels derived from petroleum. Initially, biomass was the only source of energy available to and used by man but the development of fossil fuels (coal and oil) rapidly reduced the use of biomass as energy source, especially in the developed countries.

Biogas is a clean, abuandant and renewable energy source. They do not cause environmental pollution due to SO_2, CO_2, CH_4 etc. Low-cost substrates, often wastes including municipal waste can be converted to high-value product-the biomethane- together with the cleaning up of the environment. This is the mixture of gas produced by methanogenic bacteria while acting upon biodegradable materials in an anaerobic condition. Biomethane is mainly composed of 50 to 70 percent methane, 30 to 40 percent carbon dioxide (CO2) and low amount of other gases.

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650° to 750° C. It is an odorless and colorless gas that burns with clear blue flame similar to that of LPG gas (Sathianathan, 1975). Its calorific value is 20 Mega Joules (MJ) per m^3 and burns with 60 percent efficiency in a conventional biogas stove.

Biogas technology, which converts biological waste into energy, is considered by many experts to be an excellent tool for improving life, livelihoods, and health in the developing world. Worldwide, about 16 million households use small-scale digesters, according to Renewables 2005: Global Status Report, a study by the World watch Institute. Biogas production by anaerobic digestion is popular for treating biodegradable waste because valuable fuel can be produced while destroying disease-causing pathogens and reducing the volume of disposed waste products. The methane in biomethane combusts more cleanly than coal, and produces more energy with no emissions of carbon dioxide.

Biogas is a mixture of gases that is produced from biological waste material (termed biomass).Thus, through anaerobic bacterial decomposition, raw cow manure, human faeces, and water can be converted into a gas mixture primarily composed of methane gas that can subsequently be used as burning fuel. Biogas has a calorific value of 20 Mega Joules per cubic meter (FAO, 1997) and can be used for many domestic applications such as lighting, cooking, electricity generation, or fuel for modified internal combustion engines. It has been shown that one cubic meter of biometahne could cook 3 meals for a family of 5 or 6, generate 1.25 kilowatt hours of electricity, or power a one horse power internal combustion motor for 2 hours (ITDG, 2004[1]: 3). Biomethane can be produced by methanogenic bacteria in a digester. This physical structure, invented in the 1930s and developed in the 1950s and 1980s, is essentially an underground and airtight pit that can receive animal manure, human faeces, and water to produce biomethane and potent fertilizer. Once a suitable bacteria culture has been developed inside the Digester, biological waste is mixed with water in a 2:3 ratio and held at an optimal temperature of 30-40°C for approximately 50-60 days (FAO, 1997).

The recommended daily waste loading rate, for a conventional digester, should be approximately 6 kg of manure per cubic meter of biogas desired (FAO, 1997). It should be noted however, that given the long retention time of the manure (50-60 days), the underground chamber of the digester should have a total volume 50-60 times greater than the daily volume of manure added. In order to maximize the production of biogas, the input biological waste should have Carbon-Nitrogen (C/N) content ratios of 20 to 30 (FAO, 1997). Such C/N ratios can be obtained from cattle manure and other biological wastes. The gas output of the Digester varies depending on its size. However, it has been estimated that 50-70 percent of the raw materials fed in the Digester are eventually converted to biogas (Fry, 1973: 18). The remaining raw materials are converted into sludge (a liquid-solid mixture), which has been found to be a very potent fertilizer (Fry, 1973: 25).

The objective of this study is to produce biogas as a source of energy production for developing nations using a household in Nigeria as a case study.

METHODOLOGY

There are two main phases for the construction of the underground Chinese digester used for this research work; Phase I is basically the structural concrete work of the digester. This begins with the Planning/preparation stage to the final concrete plaster application to the inside of the digester /gas dome. The importance here is that all of the concrete work was carried out continuously, day to day to avoid any delays in the concrete work. Timing was taken into full consideration and the planning/preparation of the work to be done was fully understood so that nothing will interfere with gas production, durability. Each biogas unit meet specified technical requirements for it to be water and gas tight for the unit to function properly. After all of the main structural concrete work has been completed and the “curing” process of the concrete properly stated, the Phase I construction is considered finished. The break between Phase I and Phase II is to allow for the proper curing of the concrete, a period of no less than 2-3 weeks.

The activities of Phase II are gas piping systems (from digester to the stove, manometer, gas meter, scrubbers) etc. and loading (testing for water and gas tightness).Furthermore, water and gas tightness was done before the actual loading of the digester

The Materials Used for the Construction

The different required materials were procured and all materials that were used were locally procured from material merchants in Ibadan, Nigeria. The Cow dung and its rumen were sourced from Bodija Market, Ibadan, Nigeria. However, the water hyacinth was sourced from University of Ibadan, Nigeria.The various materials used were shown in the table below:

Table 1.1: Materials for the digester

Bill of Engineering and Measurement

Quantity	**Materials**	**Unit Price**	**Amount**
25 Bags	Cement	1,700	42,500
2 Tipper	Sand	5,500	11,000
1 Tipper	Gravel	10,000	10,000
3(9 mm)	Iron rod	1,050	3,150
2	Quarter rod	900	1,800
6	1 kg silicate powder	1,500	9,000
1(13 ft)	PVC pipes	1,500	1,500
2	Labourers(block molding)	1,500	1,500
1	Carpenter(dome)	3,000	3,000
1	Iron bender(dome)	1,000	1,000
1	Materials (dome)	5,000	5,000
1	Materials for the inlet cover	4,000	4,000
1	Materials for the outlet cover	4,000	4,000
1	Wages for technician	80,000	80,000
1	Miscellaneous	20,000	20,000
		Total	**197,450**

Table 1.2: The Materials for the Piping System

Bill of Engineering and measurement

Qty	**Description of Materials**	**Unit Price**	**Amount**
10	½ inch elbow pipe	20	200
	½ inch T-pipe		
5	13 ft ½ inch pressure pipe	300	1,500
10	½ inch union	25	250
3	½ inch connector	20	60
4	Tap	200	800
2	Tongit Gum	400	800
1	Artisanal Manometer	2,000	2,000
1	Biogas Cooker	10,000	10,000
1	Scrubbers (Lime water, Finely divided iron, dessicator and activated carbon.	1,000	1,000
4	Scrubber's Containers	250	1,000
½Bag	Cement	1,000	1,000
		Total	**18,610**

The Sampling Site

The site was located at Alaka area, Orita Challenge, Ibadan.The site was considered suitable because the water table is not high and the area is not waterlogged. The town experiences two (2) seasons - rainy and dry. The raining season run from March through October, with temperatures ranging from 21°C to 34°C, rainfall from 8.4 cm to 8 cm and humidity ranging from 54 - 77%. The dry season is rather short extending from November through February. During this period, the prevailing temperature ranges from 20-35°C, rainfall from l cm to 4.6 cm and humidity from 43 -83%. The beginning of the dry season is characterized by cold humid mornings and warm afternoons, and is called "harmattan.

The Construction of the Digester

An underground biodigester made of concrete was designed and constructed following standard procedures for the household. The biodigester was dug to a depth of 1.22m. The floor was constructed with gravel, cement and sand. Poly-Vinyl-Chloride (PVC) pipes were used to connect the inlet and the outlet tanks to the digester. 3300 litres of water, 800kg of cattle and 30kg of water hyacinth were mixed together to form a slurry. A pH meter was used to measure the pH of the slurry. The slurry was used to charge the biodigester. The digester was subjected to anaerobic digestion for seven days after which the pressure rose indicating gas production in the biodigester. The biomethane produced was stored in the biodigester. The gas was monitored by with artisanal manometer.

RESULTS

The results of this research work could be divided into two phases which are; Phase I- the result of the designing and fabrication of the digester and Phase II- the result of biogas production.

Phase I: Designing and Fabrication of the digester

The Digester: The digester was inspected and no gas leakage was observed. The excavation work produced a cylindrical shaped underground digester. The flooring was saucer in shaped while the manhole cover has a dome shape. The sidewalls were made of blocks which help the digester to be water and air-tight.

i. **The Inlet Pipe:** The slurry (Cattle dung, and water hyacinth) flowed easily into the digester without any slurry leakage.

ii. **The Outlet Pipe:** The digestate flowed out through the outlet pipe without any leakage.

Phase II: Biogas Production

Gas Production: The digester produced 2.5m^3 of biogas per day. The gas produced was flammable, odourless and smokeless. The gas generated was enough for domestic activities such as cooking a variety of staple foods by a household of six people. The household used an average of 0.28m^3 of biogas per hour. The generated gas was found to be environmentally friendly as it produced a blue flame without any smoke. The household preferred biogas to other conventional ways of generating fuel since they could get the feedstock easily from a nearby farm thereby saving cost of buying fuel.

Gas Storage: The fixed dome beam top stored the gas produced and makes it convenient to store the gas since it was an inbuilt storage tank.

Gas meter: The gas meter measured the amount of biogas produced everyday. The digester produced 2.5m^3 of biogas daily.

Artisanal Manometer: The artisanal manometer checked pressure and monitored the gas produced. It indicated a low or negative value whenever there is little or no gas in the digester.

Gas Piping System: The pressure pipes experience no leakage as it passed through the digester to the kitchen where it was finally utilized.

Gas Scrubbers: The gas produced was scrubbed with lime water, finely divided iron, activated carbon and a dessicator which removed Co_2, H_2S NH_3 and water vapor respectively

Biogas Cooker: The biogas cooker produced a blue fame and was used for cooking a 3 square daily meal. The household prefers the biogas to the conventional ones.

Daily Gas Yield: The digester produced 2.5 m^3 of biogas per day. The gas was utilized by the household.

Daily Types of Food Cooked and Cooking Time: The household utilized 1.12m^3 of biogas everyday for four hours daily cooking from Monday to Friday while more biogas (1.68m^3) was used on weekends when six hours of cooking took place.