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Estimation Of The Electric Power Potential Of Human Waste Using Students Hostel Soak-Away Pits.

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Abstract: **-** With the growing demand for electric power supply in Nigeria, there is a need to look into all possible means of electricity generation especially renewable ones. It is an established fact that methane gas is a major product of the anaerobic digestion of human waste and the combustion of this gas can be used to generate electricity. This paper presents a carefully articulated approach to the technique of estimating the amount of electricity that can be generated from a specified amount of human waste. The analysis of the acquired data from a student's hostel pit toilet at the Federal University of Technology, Owerri, shows that the available biomass waste in tonnes per day from the case study area is 3.66 tonnes and the biogas accruable bi-monthly is 154.76kg capable of running a 5KW biogas generator for six (6) days.

Keywords: **-** *biomass, biogas, renewable, anaerobic, digesters, waste.*

I. INTRODUCTION

Scientific interest in the manufacturing of gas produced by the natural decomposition of organic matter was first reported in the 17th century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes[Ferguson, 2006]. In 1808, Sir Humphrey Davy determined that methane was present in the gases produced by cattle manure [Cruazon, 2007]. The first anaerobic digester was built by a leper colony in Bombay, India, in 1859. In 1895, the technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting. Also in England, in 1904, the first dual-purpose tank for both sedimentation and sludge treatment was installed in Hampton. In 1907, in Germany, a patent was issued for the Imhoff tank, an early form of digester.

Through scientific research, anaerobic digestion gained academic recognition in the 1930s. This research led to the discovery of anaerobic bacteria, the microorganisms that facilitate the process. Further research was carried out to investigate the conditions under which methanogenic bacteria were able to grow and reproduce [Humanic, 2007]. This work was developed during World War II, during which in both Germany and France, there was an increase in the application of anaerobic digestion for the treatment of manure.

1.0 Processes of Biogas production

There are four key biological and chemical stages of anaerobic digestion:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

In most cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids (VFAs) with a chain length greater than that of acetate must first be catabolised into compounds that can be directly be used by methanogens [Boone, Mah, 2006].

The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulfide, as well as other byproducts. The process of acidogenesis is similar to the way milk sours. The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pH and occurs between pH 6.5 and pH 8[Martin, 2007]. The remaining, indigestible material the microbes cannot use and any dead bacterial remains constitute the digestate.

A simplified generic chemical equation for the overall processes outlined above is represented in equation 2.14.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \qquad (1.0)$$

1.1 Biomass Power Generation

People living in countries with flush-toilets and running water produce a huge amount of wastewater daily. This is full of organic compounds that store usable energy in their chemical bonds. Several methods can be employed to harvest it for example; engineers can extract methane through anaerobic (oxygen-free) digestion, or produce electricity using microbial fuel cells.

Rural areas usually have large supplies of material crop residues and animal wastes-theoretically suitable for conversion into a usable source of energy. The process that appears to hold the greatest immediate potential for utilization of these materials as sources of fuel is anaerobic fermentation. This process, also called anaerobic digestion, converts complex organic matter to methane and other gases. It has advantages that recommend it for serious consideration:

1. It is the simplest and most practical method known for treating human and animal wastes to minimize the public health hazard associated with their handling and disposal; and
2. The residue left after removal of the gas is a valuable fertilizer that contains all the essential nutrients present in the raw materials.

The fact that organic material, rotting under conditions where it is out of contact with air, will produce a flammable gas has been known for centuries, particularly in the phenomenon of marsh gas. The occasional dancing flames of this gas (ignited, perhaps, by stray sparks from a nearby fire), seen at night, have given rise to the legends of the "will-o'-the-wisp," or fool's fire. Although it is not certain when it was first recognized that manure, if allowed to decompose in a sealed pit, would also produce a flammable gas, we know that the gas from a "carefully designed" septic tank was used for street lighting in Exeter, England, in 1895 [McCabe, Eckenfelder, 1957]. The experience must have been successful enough to encourage others, for, in the 1920s, several devices were built and used in England, specifically for the purpose of generating this gas,' which is primarily methane, the simplest organic compound of carbon and hydrogen. The process has also been utilized where energy supplies have been reduced, as in France, Algeria, and Germany during and after World War II, when methane thus produced was used to run automobiles.

In countries hampered by low natural abundance or inadequate distribution of energy supplies, methane-generating equipment has often been adapted to meet rural needs. Family-size methane-generating units have been used in diverse climates and cultures. In India, concern over the loss of cow dung for fertilizer, because of its traditional use as fuel, sparked early experiments to develop a system to provide fuel without destroying the dried dung. These experiments were initiated in 1939 at the Agricultural Research Institute in New Delhi. An account of that experience states: "The experiments resulted in the designing of a simple and easy-to-operate gas plant in which dung is fermented to yield a combustible gas which can be used as a fuel and the dung residue can be utilized as manure". The work in India continued and expanded with the encouragement of the Khadi and Village Industries Commission. In 1961 the Gobar Gas Research Station was started in Ajitmal, Etawah (Uttar Pradesh), and in 1971 it published a variety of designs for gas plants. In the years since experiments first began in India, many thousands of such plants have been built in that country most of them in rural areas and serving from one to several families.

The interest in this anaerobic digestion process is not as easily chronicled for other developing countries as it is for India, with the exception, perhaps, of Taiwan. There, experiments with the generation of working fuel from pig manure began about 1955 and developed into a program supported by the government [Ju-tung, 1965]. To date, about 7,500 such devices have been built in Taiwan as permanent adjuncts to pig-

raising operations on small and medium-size farms, although reports indicate that perhaps only half that number is actually in operation [Chan, 1983].
There are scattered reports of the use of methane generation from waste materials in other countries. Installations have been reported in Uganda [Jefferies, 1964], and Bangladesh [Chan, 1983].
Since 1971 some experiments have also been carried out on the islands of the South Pacific; a pilot project was installed on a small farm in Fiji and a successful demonstration project was operated at Port Moresby, Papua New Guinea.

Finally, in the United States and Western Europe, interest in the use of anaerobic digestion to provide fuel and safe "natural" fertilizer for small-scale use has been growing steadily for a number of years and numerous pamphlets have appeared that give more-or-less detailed instructions for building digesters [Garg, 2009].

Thus, extraction of energy from wastes by anaerobic digestion is decades old, and the general technology is well-known. It has not, however, been confined to small-scale use. Large-scale municipal digesters are used in the treatment of municipal sewage sludge, with the evolved gases satisfying part of the energy needs of the municipal treatment plant.

Common materials used for methane generation are often defined as "waste" materials, e.g., crop residues, animal wastes, and urban wastes including night soil. Some of these materials are already used in developing countries as fuels and/or fertilizers. Use of these materials for methane generation, as illustrated in Fig.1.0, will allow additional value to be gained from them while the previous benefits are still retained.

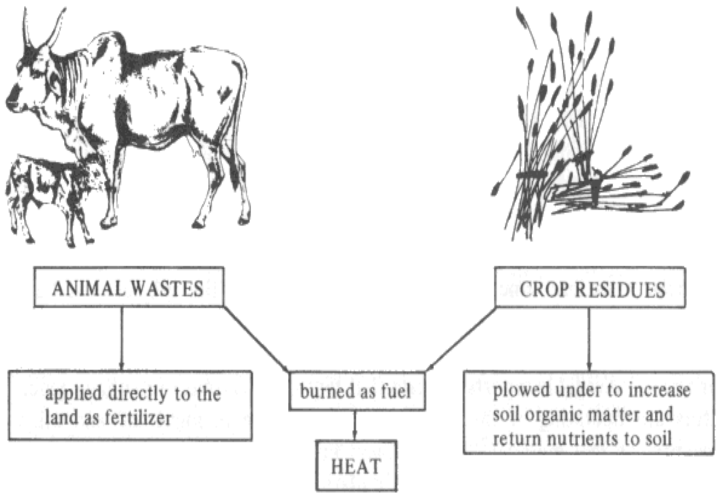

Fig.1.0: Use of Biomass as Energy Source.

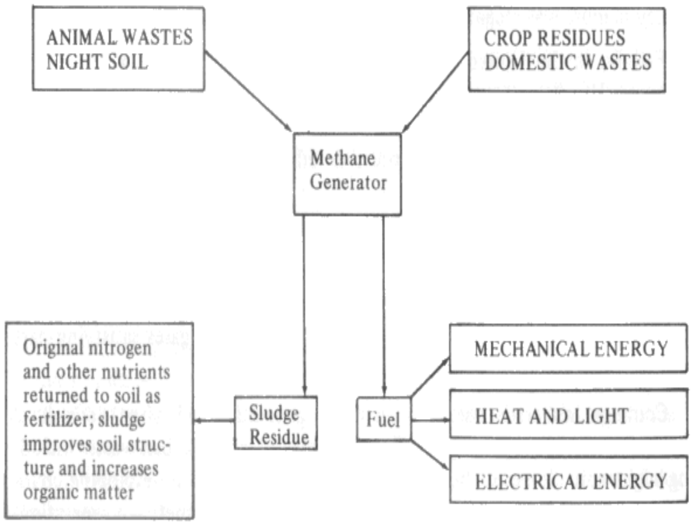

Fig.2.0: Process of Methane Generation.

In the past several years, an increasing amount of research has focused on developing and improving on these methods, as harnessed sewage power could help water treatment plants produce enough power to meet all their own consumption and even serve as a fuel source in developing countries where supplies are currently unreliable. It is necessary to know how much usable energy raw sewage holds. This was the question posed by the authors of a study published in a journal of *Environmental Science & Technology* [Mukhopadhyay, 2004]. Their answer was that wastewater likely holds a lot more than was previously thought of by Elizabeth Heidrich, a PhD student at Newcastle University in England and lead author of the new study, studied microbial fuel cells devices that generate electrical current by capturing the electrons freed as bacteria break down organic matter in wastewater. As she was preparing her doctoral research project she decided to determine how much energy engineers could count on wastewater to provide. Heidrich found only one study, published in 2004, which had tried answer to the question. The authors had tested a sample of raw municipal sewage collected from a Toronto treatment plant and, using calorimetry (the measurement of heat absorption and emission), calculated the internal chemical energy of the sample to be 6.3 kilojoules per liter. They also correlated the amount of energy found in the sample to its Chemical Oxygen Demand (COD), a commonly used indirect measurement of dissolved organic compounds. Based on this correlation, they estimated that, in all, the wastewater produced in 2004 by the world's 6.8 billion people contained a continuous supply of energy somewhere in the range of 70 to 140 Giga Watts. (One large nuclear plant produces around 1 Giga Watt). But the results of this study which Heidrich notes have been cited multiple times in the microbial fuel cell literature are problematic.

Before a sample can be tested in a calorimeter it has to be dry, and in this case the authors had dried their sample by leaving it overnight in an oven heated to 103 degrees Celsius. And because the boiling points of several organic liquids including methanol, ethanol and formic acid found in sewage are lower than 103 degrees, it is expected that there would be losses. These losses would mean the authors had not accounted for all the energy contained in the sample. So, in a similar study, the researchers collected their own samples one from a plant that treats domestic, household wastewater and another from a facility that treats "mixed" wastewater containing chemicals disposed of by industrial facilities. Instead of using an oven they freeze-dried the samples before testing them in a calorimeter. They found that the industrial sample held about 16.8 kilojoules per liter, whereas the domestic sample contained 7.6 - 20 percent more than the previous study had reported for its domestic sample. Perhaps more importantly, given that wastewater samples are highly variable, it was found that the commonly used COD measurement does not actually correlate to energy content, and thus is an unreliable metric. Had they relied on the same calculation methods employed in the previous study, they would have found only around half the energy contained in each of their samples. Thus, the older estimate likely is a "substantial underestimation."

Heidrich's method has its own limitations: The freeze-drying step takes weeks, so it cannot be relied on as a routine testing method. And although the process preserves more organic matter than does oven drying, it still causes some energetic molecules to be lost. Regardless, Heidrich notes, the study's result has immediate real-world implications. Up until this research, domestic municipal wastewater was seen as something that cannot really generate energy, so it was considered not worth the effort. Now, that thought has changed.

With an accelerating world shortage of power and rising costs of fuels, many places have started utilizing bio wastes. San Antonio generates electric power from human faeces while San Francisco is generating power from pet droppings and several large US farms utilize pig litter. Suffolk in the UK has a power plant generating 12.7 MW of energy and consumes 125,000 tonnes of poultry litter per year and encouraged by its success is now planning a human waste plant in Northampton shire. The UN is also sponsoring a project for power from poultry wastes in Bangladesh [Sujata, 2010].

Power from human wastes will be especially valuable in urban areas but all farm wastes can be effectively used. The world’s 7 billion people produce about 14 million tonnes of faeces every day and 25% of this has the potential power to produce roughly 40,000 MW of energy. India with one seventh of the world population could therefore add some 6,000 MW to her slow growing power capacity. Furthermore as the technology is quite simple and cheap much of this potential can be made available very quickly.

Rwanda has installed 20 human waste power generating plants of 500 kW each at some of their big prisons where many thousands convicted of genocide are incarcerated. These now provides about half of their electricity requirements. For this initiative, Rwanda earned the Ashden Award for Sustainable Energy with a cash component of $50,000. If Rwanda can achieve this, it is very clear that it is necessary to intensify research in this area around the world. The biogas system includes the gas production process, the use of the gas produced, and the use of the sludge remaining after fermentation is complete.

1.3 Biogas Production and Use

The production of methane during the anaerobic digestion of biologically degradable organic matter depends on the amount and kind of material added to the system. The efficiency of production of methane depends, to some extent, on the continuous operation of the system. As much as $1000m^3$ of gas (containing 50-

70 percent methane) can be produced from 1000m^3 of volatile solids added to the digester when the organic matter is highly biodegradable (e.g., night soil or poultry, pig, or beef-cattle faecal matter) for a period of 30 days [Sujata, 2010]. Combustion of about 30litres (1 ft^3) of gas will release an amount of energy equivalent to lighting a 25-watt bulb for about 6 hours [Sujata, 2010].

In general, lower gas-production rates result when the wastes are less biodegradable. In developing countries, an important consideration will be the differences in the quantity and quality of waste material produced from various sources; for example, the quality and quantity of animal manure is influenced by the diet and general health of the animals. The use to which the gas is put depends upon removal of non-combustible components (such as carbon dioxide) and corrosive components (such as hydrogen sulphide). Among the many potential uses of digester gas are hot-water heating, building heating, room lighting, and home cooking. Gas from a digester can be used in gas-burning appliances if they are modified for its use. Conversion of internal-combustion engines to run on digester gas can be relatively simple; thus the gas could also be used for pumping water for irrigation. Past experiences have shown that where methane is generated in significant quantities in rural areas of developing countries, its use is primarily for lighting and cooking.

The gas produced by digestion of organic waste is colourless, flammable, and generally contains approximately 60 per cent methane and 40 per cent carbon dioxide, with small amounts of other gases such as hydrogen, nitrogen, and hydrogen sulphide. It has a calorific value of more than 500 Btu/ft^3 (18,676kJ/m^3). Methane itself is a non-toxic gas and possesses a slight but not unpleasant smell; however, if the conditions of digestion produce a significant quantity of hydrogen sulphide, the gas will have a distinctly unpleasant odour.

1.4 Biogas Resource Evaluation

The production of methane during the anaerobic digestion of biologically degradable organic matter depends on the amount and kind of material added to the system. The efficiency of production of methane depends on the continuous operation of the system. As much as 1000*l* of gas (containing 50-70 per cent methane) can be produced from 1000*l* of volatile solids(1000kg/m^3) added to the digester when the organic matter is highly biodegradable (e.g., night soil or poultry, pig, beef-cattle faecal matter or human municipal waste).

1.5 Biomass Sources in FUTO

The biomass in FUTO ranges from cow dung, green leaves and municipal solid waste (MSW). With the number of students living in the school's hostel, some amount of human waste can be generated.

It was gathered from the director of Estate and Works Department, that the septic tanks are usually dislodged every two months. The dimensions of the septic tanks used at the various hostels were received from the Physical Planning and Development (PP and D) Unit in the Senate building. This enabled the calculation of the volume of the waste every two months.

The cost at which the dislodgement is done was found from the Dean of Student Affairs to be fifty thousand naira per pit. This value is required by the software for the effective implementation of the cost analysis.

1.6 Calculations on Biogas Resources

The following analytical results were obtained from the anaerobic digestion of biomass wastes using human wastes to produce methane:

Since 1kWh = 3415btu, a simple gas turbine has a fuel consumption of 3415/0.34 =10000Btu/kWh, where 0.34 is the plant factor.

Net heating value of methane = 21433Btu/pound

Thus the methane consumption in a simple gas turbine would be:

10000/21433 = 0.47pounds/kWh = 0.21kg/kWh

1000litres = 1m^3

22.4litres = 1*mol*

Molar mass of methane is 16g per mole

Therefore $16/1\text{mol} \times 1000\text{l/m}^3 \times 1/22.4\text{l} = 714\text{g/ m}^3$

Volume of human waste from hostel A = 43.2 m^3

Volume of human waste from hostel B = 43.2 m^3

Volume of human waste from hostel C = 43.2 m^3

Volume of human waste from hostel D = 43.2 m^3

Volume of human waste from hostel E = 43.2 m^3

Volume of human waste from PG hostel = 3.75m^3

Total volume = $43.2 \times 5 + 3.75 = 219.75\text{m}^3 = 219.75\text{ m}^3$

$219.75\text{ m}^3 \times 0.714$ = 154.76kg

If 1000 litres of human waste produces 700 litres of biogas, 219.75 m^3 will produce 153.83 m^3 of biogas (since 70% of biogas can be produced from any given mass of human waste)[Martin, 2007]. Energy produced from 154.76kg of biogas will be 154.76kg /0.21kg/kWh = 736,95kWh

Recommending a 5kW biogas generator, the generator can run for 736.95/5 = 147.39, 147.39/24h = 6.14 i.e. approximately six days.

The density of human waste is approximately equal to the density of water = 1000kg/ m^3.

Mass of human waste = 1000 × 219.75 = 219750kg

Since the hostels' septic tanks are dislodged after every two months, the mass per month = 109875kg

The mass per day = 3662.5kg. The available biomass waste in tonnes per day is given as: 3662.5/1000 = 3.66 tonnes per day and this will vary according to when students are around in school.

II. CONCLUSION

From the results obtained from this research, there is a clear indication that human waste is capable of being a source of biogas which can be converted to a useful amount of electric energy. This type of energy source is renewable and this makes it environmentally friendly. The sludge which is usually the waste from the anaerobic digestion process can also be a very useful source of natural manure. Animal droppings can produce larger amounts of biogas than human waste because of their high fiber content. Therefore, it will not be out of place to recommend that large poultry farms and cattle ranches be put in place to support the biogas production process in the school.

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