Evaluating the biogas yield and design of a biodigester to generate cooking gas from human faeces

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Abstract

Erratic power supply in the halls of residence in the University of Ibadan has been the major source of series of protest and students' provocation on campus. Electric power is the only cheap source of energy that students use to heat and cook their food. The University claims to incur huge cost on electricity supply. An alternative energy is sought from the biogas generated from the digestion of faeces of members of the halls. The large population of the halls could be taken advantage of, as more quantity of faeces is expected daily. The first batch of the experiment, after a few days has stopped producing gas. This, as was later discovered, was as a result of low moisture content of the systems. Digester II of the batch II experiment yielded 0.00227m^3 of biogas, out of which 0.0013 m^3 is expected to be methane gas. A 540m^3 yearly production of biogas is projected, which gave a payback period of 15 years for the cost of construction of the digester. This could be considered a free renewable energy as human faeces is a waste and readily available. Environmental impact of the methane generated and vented into the atmosphere has higher Global Warming Potential (GWP x21) than Carbon (IV) oxide.

Keywords

Digester; Faeces; Biogas; Methane; Global warming potential; Payback period; Renewable energy environmental impact

Introduction

Over the past decades demand for energy has grown, and is projected to continue growing, drastically around the world. This demand has been met largely by fossil fuels such as coal, oil, and natural gas. The world's energy supply is based largely on fossil fuels and nuclear power, these are sources of energy that will not last forever and which has even proved to be major causes of environmental problems, [1, 2, and 3]. It is well established that the use of fossil fuel not only causes resources exhaustion but is always accompanied by environmental problems at local, regional and global levels ranging from deforestation, air and water pollution and global warming [4, 5]. It is therefore necessary to find appropriate energy solutions that will fuel economic growth and increase social equity because the current patterns of energy consumption are not only polluting and unsustainable, but are also characterized by inequity in consumption and access [6]. The development of an alternative and/or renewable energy supply source might be the panacea [7, 8]. The associated harmful environmental, health and social effects with the use of traditional biomass and fossil fuel have enhanced the growing interest in the search for alternate cleaner sources of energy globally [9]. The development of renewable energy such as biofuel is believed to offer developing countries some prospect of self-reliant energy supplies at both the national and local levels. In addition, this approach might also offer potential economic, ecological, social, and security benefits [10]. Biogas generation is a chemical process whereby organic matter is decomposed.

Anaerobic Digestion is a biological process that happens naturally when bacteria breaks down organic matter in environments with little or no oxygen. The anaerobic digestion of waste organic materials has two advantages, i.e. treating waste and generating biogas which can be used as alternative energy source [11, 12]. Anaerobic digestion produces a biogas made up of around 60% methane and 40% carbon dioxide (CO_2) [13]. This can be burned to generate heat or electricity or can be used as a vehicle fuel. As well as biogas, anaerobic digestion produces a residue called digestate which can be used as a soil conditioner to fertilize land. Animal waste like cow dung, chicken remains, pig faeces have been used on farms for the generation of biogas. Little effort has been put into the use of human faecal deposit for biogas generation. Microorganisms already present in the organic matter digest the material in the presence of little or no oxygen. The digestion process has the aerobic phase wherein the oxygen already present in the system is used up by the bacteria that carry out the hydrolysis, and the anaerobic phase wherein the methanogens convert the end product of hydrolysis into methane and carbon dioxide.

Biogas can be realized from the anaerobic fermentation of organic matter like plant remains and animal wastes. The digestion processes have been divided into four phases – hydrolysis, acidogenesis, acetogenesis and methanogenesis. The conditions of the digestion is classified based on the temperature at which they occur into psychrophilic (<20°C) mesophilic (20°C – 45°C) and thermophilic (>45°C) [14].

Septic tanks and sewage systems cited in residential homes have vents through which the gas generated from the fermentation of the faeces is allowed to escape into the atmosphere. Failure to install the vent would eventually lead to a cleavage of the soak-away pit. This means, a huge amount of energy what is being vented into the atmosphere. Adewole and Ismail (2012) wrote that, the gas released does not only amount to waste of useful energy, it also contributes to the global warming. Raw methane gas has a higher global warming potential than carbon (IV) oxide (GWP x21) and carbon (II) oxide which are the end products of any combustion process [15].

Integrating the energy demand issue with what has been observed; this research was launched to evaluate the biogas yield from human faeces. This, we consider would save the University lot of cost and resources.

Biogas production from organic matter is being embraced over the globe to not only serve as alternative energy for several uses, but also to conserve natural resources and protect our environment from Green House Gases from fossil fuels. This work considers the prospect of generating biogas from human waste for cooking in the halls of residence in the University of Ibadan. A thorough review of literature on biogas production from different substrate reveals that yield of biogas from human faeces is found low due to low Carbon-Nitrogen(C/N) ratio and low daily faecal production by human. The biogas substrate has to be supplemented with a supply of grass, sawdust or paper to improve the yield.

This research aims at looking at alternative source energy due to the erratic power supply, which has been a major source of series of protest and students' provocation on campus, it evaluates the yield of biogas from human faecal deposit using different additives to supplement and improve the biogas yield of human faeces.

Materials and method

The experiment was conducted in two batches. Five 2l and two 3.5l plastic containers were used as a batch-type digester and a urine bag connected to the digester served as a gas holder. The digesters were sealed using top bond glue and the openings around the gas holder inlet was sealed with a mixture of smooth sawdust and top bond glue. Shaking the containers was the manual method adopted in agitating the system.

Batch I consist of the five 2l digesters while batch II consist of two 3.5l digesters. Four of the batch I samples had additives to alter the carbon-nitrogen (C/N) ratio of the deposit.

High carbon compounds have been reported to increase the carbon-nitrogen ratio. Charcoal and sawdust were the high carbon compounds used. Water hyacinth provides microorganism that helps in the first phase of the digestion and was therefore added to another sample to observe the result. Methanogens convert acetic acid, carbon IV oxide and hydrogen in the methane generation. Lime, which is a good source of acid, was added to another sample.

All the samples in the batch I digesters dried up after about one week and this precipitated setting up the batch II digesters. The procedure of the experiment is described as follows.

Batch I experiment

Aim: to confirm the biogas yield of human faeces and to verify additional material that needs to be added to improve the yield of biogas production from human faecal deposit.

Materials: five 2l plastic containers (bio digester), 2000mL urine bags (gas collector), electric bulb (heater), top bond glue and sawdust. Figure 1 shows the schematic representation of the experimental set-up.

Additives: sawdust, charcoal, lime and water hyacinth.

Table 1. Samples arrangement

Sample	Constituents	Volatile solid waste (g)	Water (g)	Mass of additive (kg)
A	Faeces + water	282.00	108.00	Nil
B	Faeces + sawdust + water	330.86	400.00	347.02
C	Faeces + charcoal + water	350.00	300.00	235.00
D	Faeces + water hyacinth + water	200.00	400.00	300.00
E	Faeces + lime + water	340.00	200.00	260.00

Procedure: The empty containers and urine bags were separately weighed and the masses noted m_c. Samples of human faecal deposits with masses of volatile solid as indicated in Table 1 were collected into the different containers. Water and other materials were added as shown in Table 1. Sample A was left as a control for the experiment.

The entire arrangement was then sealed using a top bond glue to provide the anaerobic environment for the digestion to take place. And each arrangement was afterwards weighed and the total mass noted.

All digesters were then placed into a big container and a 60W bulb was installed in the container to generate heat to increase the temperature.

Observation: After two days, the sample with lime was observed to generate some gas followed by the one without additive. All samples dried up due to insufficient water and smallness of the containers used as digester.

The water added to the samples was suspected not to be enough to create the moist environment for proper digestion of the substrate. This is due to the size of the digester used and the quantity of additives added to each.

Batch II experiment

Aim: To increase the moisture in batch I systems and to further verify the biogas yield from human faecal deposit with sawdust additive. We also aim to verify the need for priming a digester at the initial stage using cow dung.

Materials: Two 3.5l plastic containers (bio digester), 2000mL urine bags (gas collector), top bond glue and sawdust.

Additives: Sawdust.

Procedure: Samples of volatile solid deposits were collected in the two containers. Table 2 gives the measurement taken before and during the experiment for digester I and II, respectively.

Sample I contains pure faeces and 1.4 liters of water. 10.2g of cow dung was added to supply the micro-organisms to start up the digestion process.

Sample II contains pure faeces and 1.5 liters of water. 150g of sawdust was added to increase the C/N ratio.

Table 2 gives the measurements taken in the course of the experiment.

Table 2. Measurements for batch II experiment

	DIGESTER I		DIGESTER II	
Materials	**Initial**	**Final**	**Initial**	**Final**
Empty container(m_c)	88.50 g	88.50 g	136.30 g	136.30 g
Urine bag (m_{ub})	34.60 g	34.61 g	31.94 g	33.40 g
Water (m_w)	1400.00 (1.42l)	NA	1500.00 g (1.5l)	NA
Mass of volatile solid faeces (mvsf)	411.80 g	NA	649.00 g	NA
Mass of additive	10.20 g (cow dung)	NA	150.00 g (sawdust)	NA
Total mass of set-up	**1942.44 g**	**1942.44**	**2467.24 g**	**2467.24 g**

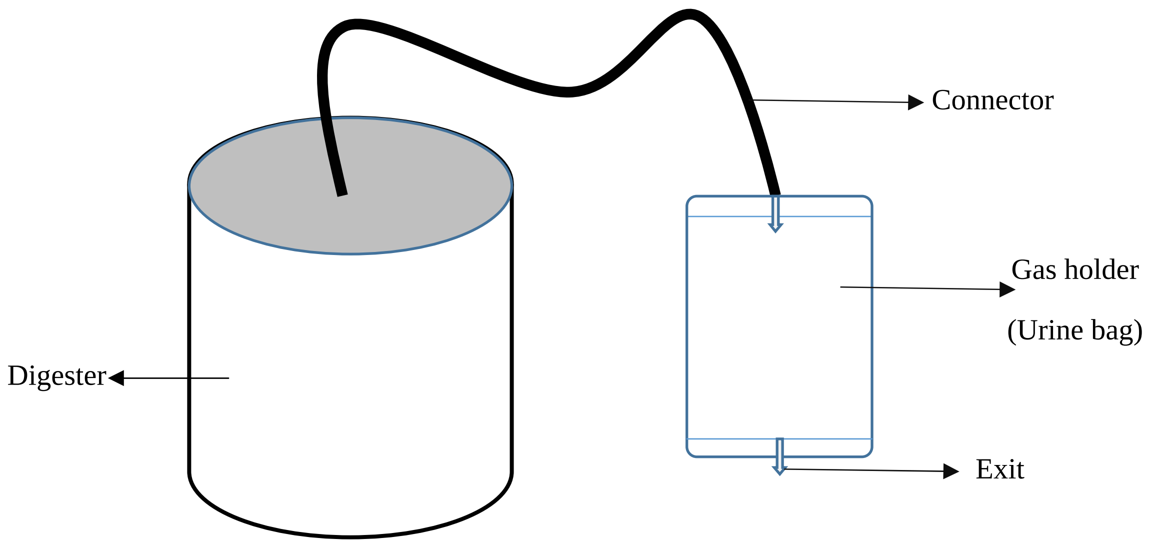

Figure 1. *Schematic representation of experimental set-up*

Results

The experiment was terminated on the 34th day – Retention time (T_r) is 34 days. The masses of the gas holder were afterwards weighed and the mass of the gas generated were obtained therefrom. The temperature range maintained in the digester during this period was between 34°C and 42°C.

Digester I did not produce gas.

Gas yield from digester II was analyzed as follows.

The following expressions were be used in determining and analyzing the gas yield of the batch II digesters.

Parameter – abbreviation (units of measurements)	Equation	Value
Total mass of biogas produced (g)	$m_{g\tau} = m_{ub2} - m_{ub1}$	1.47
Volume of biogas produced (l)	$v_{g\tau} = p_i m_i \rho_i$	2.27
Mass of gas generated per unit mass of faeces	$\frac{m_{g\tau}}{m_{vsf}}$	0.0023
Volume of biogas per unit mass of volatile solid (m^3/kg)	$\frac{v_{g\tau}}{m_{vsf}}$	0.0035
Average rate of biogas generation (l/day)	$r_{gT} = \frac{v_{gT}}{T_r}$	0.067
Yield of methane gas (g)	$m_g = 0.6 m_{g\tau}$	0.882*
Mass of methane gas per unit mass of faeces	$\frac{m_g}{m_{vsf}}$	0.0014
Volume of methane gas (m^3)	$v_g = \frac{m_g}{\rho g}; \rho_m = 0.66 kg/m^3$	0.0013
Methane gas per unit mass of volatile solid deposit (m^3/kg of volatile solid)	$\frac{v_g}{m_{vsf}}$	0.002
Average rate of methane gas production (m^3/day)	$r_g = \frac{v_g}{T_r}$	$3.93e^{-5}$
For 2000 (N) persons being considered in our design Using an average of the faecal deposit for digester I and II which is 530 g		
Total volatile solid deposit per day (kg)	$M_f = N m_{vsf}$	1060
Total expected volume of methane gas per day (kg)	$\frac{N m_g}{m_{vsf}}$	1.44
Total expected volume of methane gas generated per day (m^3/day)	$M_f = \frac{v_g}{m_{vsf}}$	2.125
The students spend an average of four months on campus per semester. Two semesters amount to months. Assuming a 30-day month		
Total volatile solid deposit per year (kg)	$M_{fT} = M_f T$	254 400
Total expected volume of methane gas per year (kg)	$M_g = M_{f\tau} = \frac{m_g}{m_{vsf}}$	356.16
Total expected volume of methane gas generated per year (m^3/year)	$V_g = \frac{M_g}{\rho_m}$	536.64
Mass of biogas yield (kg)	$M_{g\tau} = \rho_{g\tau} V_{g\tau}$	

Between 0.02 m^3 and 0.028 m^3 of biogas is produced per kilogram of faecal deposit of

humans [14]. Retention time is also between 30 – 50 days. Working by this result:

÷ Volume of biogas yield for 254 400 kg = 5088 m^3

÷ Mass of biogas yield for 254 400 kg = 3358.08 kg

÷ According to [16], 0.26m^3 per capital is required per day.

÷ Gas demand of 2000 persons =520 m^3/day

÷ For how long will a 5088 m^3last = 5088/520 m^3 = 9.78 days

Discussions

Batch I

Digestion of human faeces requires more than 50% of water to make the system moist enough for proper digestion to occur.

Batch I of the experiment failed due to the low water content of the substrate. Samples in this batch had sawdust, charcoal, water hyacinth and lime to see variations in the yield of biogas with the different additives.

It takes a minimum of thirty days before a substantial production of biogas starts. The Hydraulic Retention Time is between thirty and fifty (30-50) days in the mesophilic condition. Though, a lower retention time could be achieved under thermophilic condition. It was after the failure of the first batch that the second batch was started. This left little time to prepare as much sample of the first batch in the second batch.

Batch II

The challenge encountered in the batch I experiment was addressed and the digester II of the batch II experiment produced gas as it has been quantified in Table 2.

Kossmann et al. (1999) gathered from different sources, that the nitrogen content of human faeces (night soil) is between 6.0% and 7.1% [14]. This is high as compared to manure from other animals. The high nitrogen content produces excess ammonia. The methanogens need ammonia to perform properly. However, same ammonia, in excess, is toxic to the microorganisms.

The failure of digester I is attributable to the excess nitrogen content of the human faecal deposit. This is the reason why the other digesters in batch I had additives.

Digester II of the batch II had sawdust as an additive. The digester yielded 1.47 g of biogas after 34 days of digestion. Longer retention time would have given room for more gas production.

Conclusions

The research revealed that using a sample of feaces from one person yielded 1.47 g or 2.27 L of biogas out of which an average of 60 percent is methane. A projection of 540m^3/year is expected from the biodigester to be installed in the hall.

With this amount of methane yielded, a biodigester plant designed for the hall will go a long way to solve the energy crises in the campus. However, a longer retention time being given for the digestion would result in a better yield of the digester.

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