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Comparative study of biogas formation using different locally sourced substrate

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Abstract

Co-digestion method of biogas production has proved to enhance the quantity of biogas produced. Co-digestion simply means the combination of two or more substrates together in anaerobic fermentation. For containers 1, 2, 3 and 4; there is a reasonable amount of gas production for container 4 which is for co-digested substrates. The ratio of the 4 containers at day 15 shows 0.10: 0.11: 0.12: 0.16: and 0.20. This shows that containers which represent cow dungs, poultry dungs and sewage for day 3, 6, 9, 12 and 15 are in the percentage of 14.49%, 15.94%, 17.39%, 23.19% and 28.99%. The 28.99% explains why co-digestion produces more biogas.

Keywords: Substrate; Co-Digestion; Anaerobic; Biogas; Methanogen; Fermentation

1. Introduction

Biogas is a term used to describe a mixture of gases produced during the anaerobic digestion of biological or organic materials or waste (Choong *et al* 2016). By anaerobic it means oxygen is not needed for the reaction to take place. In a small scale farm, biogas can be made from the anaerobic decomposition of organic material such as livestock waste (urine, dung) and waste feeds. Biogas is produced when bacteria known as methanogen bacteria ferment or breakdown the organic material in the absence of oxygen (Jan & Felix .; 2011). Methanogen bacteria prefer certain conditions and are sensitive to the microclimate within the digester. Methanogen bacteria develop slowly and are sensitive to sudden changes in temperature (Dhaked *et al* 2010). For example, a sudden fall in the slurry temperature by even 2ºC may significantly affect their growth and gas production rate. Biogas consists of methane (40-70%), also known as marsh gas or natural gas (CH_4), 30 to 40% carbon dioxide (CO_2), and low amounts of other gases such as hydrogen, nitrogen and hydrogen sulphide. Biogas is about 20% lighter than air and has an ignition temperature in the range of 650° to 750° C. It is odourless (after burning) and colourless and it burns with a clear blue flame similar to that of Liquid Petroleum Gas (LPG) gas (Kahn *et al* 2016).

Biogas is a renewable fuel because it is produced from waste treatment. Biogas is produced inside a plant known as a bio digester (Karanja, and Kiruiro,. 2003). Biogas production and technology has been around for a long timed and its use has been implemented all over the world. According to Harris (2015), anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century AD. In the 12th Century, Marco Polo, the famous merchant from Venice reported the use of covered sewage tanks. In the 18th century, it was determined that flammable gases could evolve from decaying organic matter, and that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced. In Europe in 1808, Sir Humphrey Davy determined that methane was present in the gases produced during the anaerobic digestion of cattle manure. In 1884, Pasteur researched on biogas from animal residues and proposed the utilization of horse litter to produce biogas for street lighting (Moestedt *et al* 2016).

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In 1890, methane was first recognised as having practical and commercial value in England, where a specially designed septic reservoir was used to generate gas for the purpose of lighting. In India, the first digestion plant was built at a leper colony in Bombay, in 1859. In the 1950s, the development of simple biogas plants for rural households started (deVrieze *et al* 2012). One of the main benefits of biogas production and technology is its ability to generate biogas which can be used as replaceable source of energy for the environmental unfriendly methods. The main output of a biogas plant is the methane gas which is valued for its uses in cooking and lighting, and the slurry for its soil nutrients or fertilizing properties. It can also be used as fuel for combustion engines and for absorption fridges. However, fridges are less suitable for domestic biogas as they require large quantities of gas and/or purified gas which is maintained at a constant pressure. Also, contrary to popular believe, it is not feasible to compress biogas into a liquid form and store/transport it in gas cylinders.

A biogas production plant normally has five major components. The required quantity of substrate or feedstock is mixed with water and fed to the digester through the inlet tank. Once the mixture is digested, gas is produced and collected in the dome, also known as the gasholder (Maciacorral *et al* 2008). The digested slurry flows to the outlet tank through the manhole and eventually ends up in the compost pit where it is collected and composted. The gas is supplied to the point of application through the pipeline. The components as described above include:

- Feedstock,
- Water,
- Digester,
- Reaction And
- Collection Tube.

1.1. Inputs for biogas production

In principle, any biodegradable organic material can be used as substrate for processing inside the bio digester. If you purchase or transport the inputs for biogas production over a large distance, then the economic benefits of biogas production would be adversely affected. If however, the inputs are easily available within the homestead, then biogas production has great economic value

1.2. Microbiology and chemical reaction in anaerobic digestion

1.2.1. Hydrolysis

This is a process where complex macromolecular organic matter comprising of carbohydrates, proteins and fats is subjected to enzymatic degradation and transformed to monosaccharides, amino acids and long chain fatty acids (Karanja *et al* 2003)

1.2.2. Acidogenesis

This is also termed fermentation. It is generally defined as an anaerobic acid-producing microbial process without an additional electron acceptor or donor (Gujer and Zehnder, 1983). The monosaccharides and amino acids resulting from hydrolysis are degraded to a number of simpler products such as volatile fatty acids (VFA) including propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and acetic acid (CH_3COOH) (Batstone *et al.*, 2002).

1.2.3. Acetogenesis

The products of acidogenesis cannot be utilised directly by the methanogens and must be degraded further in a subsequent process that is referred to as acetogenesis (Björnsson *et al.*, 2000).

1.2.4. Methanogenesis

This is step in which the fermentation products such as acetate, H_2 and CO_2 are converted to CH_4 and CO_2 by methanogenic archaea which are strict obligate anaerobes (Björnsson *et al.*, 2000; Pavlostathis and Giraldo-Gomez, 1991).

1.2.5. Factors that Facilitate or Hinder Anaerobic Digestion

There are a number of factors that hinder or facilitate anaerobic digestion. These factors are: Carbon/Nitrogen Ratio, Dilution and Consistency of Inputs, Volatile Solids, Temperature, Loading rate, pH Value,Retention time, Toxicity.

Aims and objectives of investigation

To used different or combination of locally sourced waste in biogas production

To compare the volume of gas produced so as to be able to suggest which substrate should be used.

2. Materials and methods

2.1. Sample collection

The samples used in this research/investigation include (1) cow dungs (2) poultry dungs (3) sewage from underground household sewage tank. These three samples were taken to the research site immediately after collection from the sample site. Cow and poultry dungs were collected using empty rice bag. For the sewage from underground tank, it was collected using a 25 liter capacity bucket because it is in semi-liquid form.

2.2. Physical analysis of the three samples

Temperature and pH of the samples were tested using thermometer and pH meter. The values were recorded and shown below.

Sample	Nature of sample	pH of sample	Temperature of sample(^{0}C)
Cow dungs	Soft/solid	6.7	28
Poultry dungs	Soft/semi powdered	6.3	32
Sewage from	Watery	7.3	35

2.3. Slurry preparation and digester fabrication

The digesters were fabricated using an empty paint bucket. They were made in such a way that they are water and air tight. These were shown in figure 1 below.

The slurry for anaerobic digestion were prepared as follows

- 1000g of cow dungs was mixed with 5 liters of water and thoroughly mixed to ensure homogeneity.
- 1000g poultry dungs was mixed with 5 liters of water and thoroughly mixed to ensure homogeneity.
- Coming to the sewage from underground tank; because it is in semi-liquid form, a small calibrated plastic bucket was used to transfer 3 liters of it and mixed with 2 liters of water.
- Combination of the three samples (500g each were mixed with two liters of water)

The materials used are follows

- Thermometer
- pH meter by Hana
- Electronic weighing balance by Hana
- Locally purchased bucket.

2.4. Introduction of the slurry into the digester

At the end of slurry preparation, they were poured into the digester and labeled as follows.

- D1(Digester 1) = For slurry made from cow dung
- D2 (Digester 2) = For slurry made from poultry dung
- D3 (Digester 3) = For slurry made from sewage
- D4 (Digester 4) = For slurry made from combination of the three.

The four (4) digesters were kept in an open place where they will have contact with sunlight. But a shade was used over them. Plastic hose were used to connect the digesters to the two liter gas collection plastic with valve. This was done by connecting the hose to the gas outlet

2.5. fermentation, monitoring and measurement

The digestion processes were monitored and the weight of the gas collection container determined at 3 days interval 15 days. The weight of the empty containers were measured and taken at day zero and recorded as M_0**.** Others were recorded as M_3, M_6, M_9, M_{12} and M_{15}. The gas collection containers were kept at about 2 feet below the digester. Weight of the gas was determined by subtracting the weight of the container at day zero from the weight at other days like; weight of gas on day 3 is M_3-M_0.

3. Results and interpretation

The results obtained were as follows using the electronic weighing balance and recording accordingly.

Table 1 Raw Measurement of Gas Collection Container From Day 0 To Day 15

DIGESTER	WEIGHT AT DAY ZERO (in Kg)	WEIGHT AT DAY 3 (in kg)	WEIGHT AT DAY 6 (in kg)	WEIGHT AT DAY 9 (in kg)	WEIGHT AT DAY 12 (in kg)	WEIGHT AT DAY 15 (in kg)
CONTAINER 1	0.0983	0.1122	0.1200	0.1370	0.2000	0.2308
CONTAINER 2	0.0956	0.1201	0.1603	0.1750	0.2150	0.2355
CONTAINER 3	0.0980	0.1823	0.1995	0.2000	0.2200	0.2410
CONTAINER 4	0.0977	0.2000	0.2153	0.2200	0.2608	0.3000

Table 2 Calculated Measurement of gas in gas collection container from Day 0 To 15

DIGESTER	WEIGHT AT DAY ZERO (in Kg)	WEIGHT AT DAY 3 (in kg)	WEIGHT AT DAY 6 (in kg)	WEIGHT AT DAY 9 (in kg)	WEIGHT AT DAY 12 (in kg)	WEIGHT AT DAY 15 (in kg)
CONTAINER 1	0.0000	0.0139	0.0221	0.0324	0.1018	0.1325
CONTAINER 2	0.0000	0.0245	0.0645	0.0794	0.1199	0.1399
CONTAINER 3	0.0000	0.0843	0.1015	0.1020	0.1220	0.1430
CONTAINER 4	0.0000	0.1020	0.1175	0.1223	0.1630	0.2027

The tables above are for the raw data measured and calculated. Table 1 shows the measurement obtained from the gas collection container. The measurement was done on day 0-15. Table 2 shows the calculated volume of gas produced. This was done by weighing the container first which is recorded as M_0. At day 3, it was recorded as M3. The volume of the gas in the container was determined as follows

M_0-M_0 for day 0

M_3-M_0 for day 3

M_6-M_0 for day 6

M_9-M_0 for day 9

M_{12}-M_0 for day 12

M_{15}-M_0 for day 15

From the graph in figures 1-4, it shows significant increase in the biogas production. Container 3 and 4 shows the highest biogas production for sewage and combination of the substrate also known as co-digestion as suggested in a research done by Kazda et al 2012;, Montalvo et al 2016. Studies demonstrated that using co-substrates in anaerobic digestion system improves the biogas yields due to the positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates (Tamrat et al 2013). In a study carried out by Adelekan and Bamgboye (2009) on the different mixing ratios of livestock waste with cassava peels, the average cumulative biogas yield was increased to 21.3, 19.5, 15.8 and 11.2 L/kg TS, respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava peel was mixed with cattle waste. In another report, co-digestion of cow dung with pig manure increased biogas yield as compared to pure samples of either pig or cow dung. Comparing to samples of pure cow dung and pig manure, the maximum increase of almost seven and three fold was respectively achieved when mixed in proportions of 1:1 (Marnon et al 2012;, Montalvo et al 2016;, Muller at al 2010). Co-digestion with other wastes, whether industrial (glycerin), agricultural (fruit and vegetable wastes) or domestic (municipal solid waste) is a suitable option for improving biogas production (Amon *et al*., 2006; MaciasCorral *et al*., 2008; El-Mashad and Zhang, 2010; Marañón *et al*., 2012).

3.1. Co-digestion performance and combination effect

The co-digestion of three substrates (cow dungs, poultry dungs and sewage) was performed and biogas productions from the biodegradation of organic matter were compared with pure cow dung, poultry and sewage. The ratio of the individual substrate to the co-digestion for the day 3-15 shows

(Cow:poultry: sewage: Mixed)

Day 3 (0.0139:0.0245:0.0843:0.1020)

Day 6 (0.0221: 0.0645: 0.01015: 0.1175)

Day 9 (0.0324: 0.0794: 0.1020:0.1223)

Day 12 (0.1018: 0.1199: 0.1220: 0.1630)

Day 15 (0.1325: 0.1399: 0.1430: 0.2027)

It was also observed that the quantity of gas produced between day 6 and 9 was affected. This could be attributed to weather as there was not enough sunlight as It rainy on that day. This supported that temperature is one of the factors for digester to function well as said by Jianzheng *et al*., 2011.

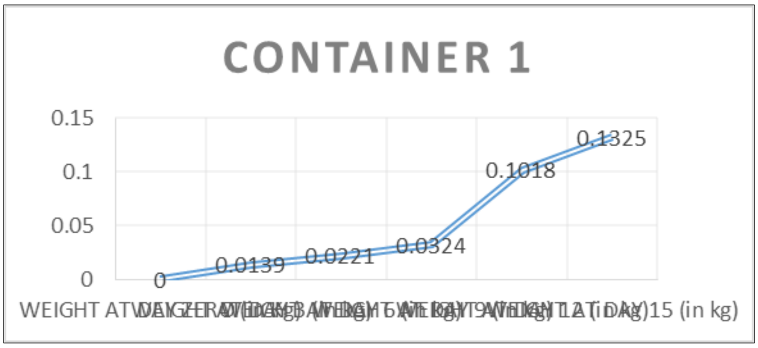

Figure 1 Biogas production in container 1 for day 0-15

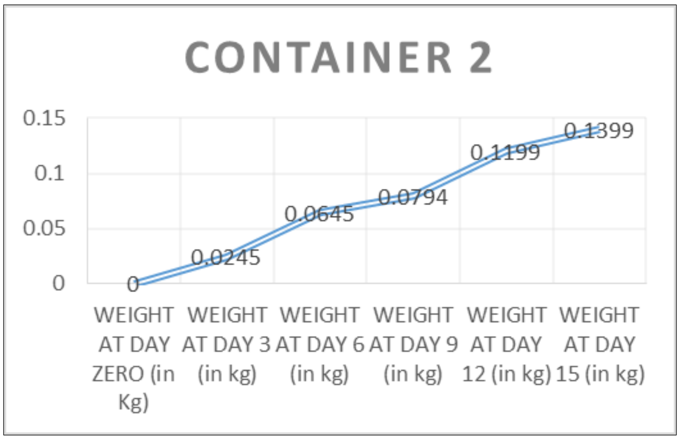

Figure 2 Biogas production in container 2 for day 0-15

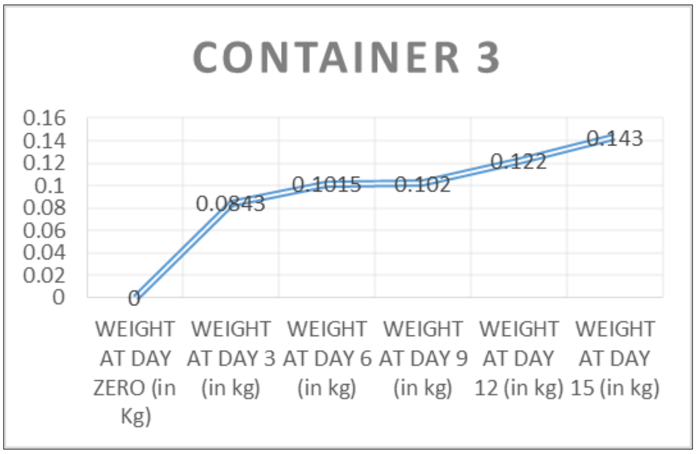

Figure 3 Biogas production in container 3 for day 0-15

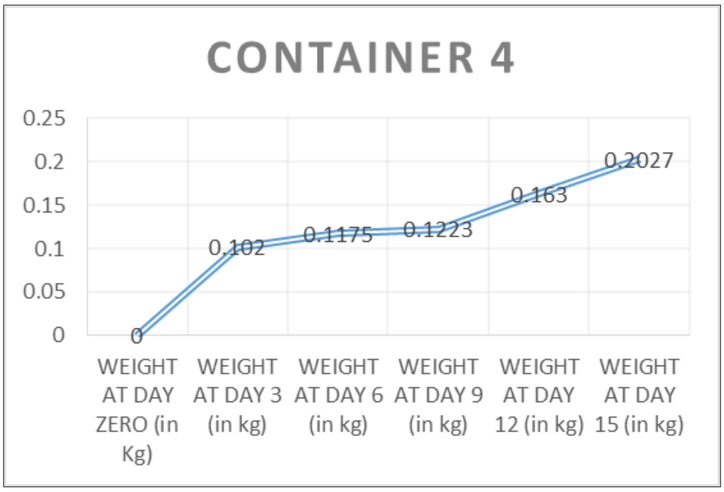

Figure 4 Biogas production in container 4 for day 0-15

4. Conclusion

Biogas formation can be achieved using locally sourced substrate or biomass (Chen et al 2014). In this research, comparison of the individual substrate and the mixure of the three showed that poultry dung produced higher than cow dung. But it was observed that for a maximum production, co-digestion technique should be used. This complied with what was suggested by Tamrat *et al* 2013; Organic kitchen wastes co-digested with cattle manure improved the biogas potential compared to cattle manure alone. The co-digestion of rumen fluid inoculated CM and OKW with mix ratio of 50:50, gives biogas yield earlier and highest average daily and cumulative biogas yield were obtained from the co-digestion of rumen fluid inoculated CM and OKW with 25:75 ratio.

Compliance with ethical standards

Disclosure of Conflict of interest

No conflict of interest to be disclosed.

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