Biogas Production in a Portable Anaerobic Digester

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Abstract

The objective of this proof of concept study is to make a prototype of an anaerobic digester to produce biogas from kitchen waste in batch mode. The insight and outcome from this work will be used for installing a scaled up facility to power a residential area or community neighborhood. In these localities, kitchen/food waste is one of the potential sources for biogas production. In anaerobic digestion, biogas is produced by the degradation of the organic food or vegetable waste by bacteria in the absence of air. The biogas that is formed is primarily composed of 55% methane and around 40 to 45% of carbon dioxide. The biogas after cleaning can be used for power generation. A series of trials were made with different feedstock in different proportion in a portable digester to observe biogas yield and the residence time needed for each feedstock combination to yield biogas. Containers of capacity 8 L, 20L and 50L were used. Measophylic temperature range is maintained and cow dung has been used as an inoculum. The biogas produced was qualitatively observed using syringe and plunger method. The scope of this undergraduate project is to qualitatively arrive at the insights on using various feedstock combinations and its effect on biogas generation.
Keywords: Biogas Production, Portable Anaerobic Digester

I. INTRODUCTION

Biogas production by anaerobic digestion from renewable feedstock has become one of the potential technologies to address the present energy crisis and subsequent emission issues. This technology is environmentally friendly and is in use over the past several decades. Apart from generating fuel for power, the organic wastes that are treated would otherwise be contributing to global environmental pollution.

A. Anaerobic Digestion

Anaerobic digestion is a series of biological processes that use a diverse population of bacteria to break down organic materials into biogas, primarily methane and a combination of solid and liquid effluents, the digestate. It occurs in the absence of free oxygen. The organic materials are composed of organic compounds resulting from the remains or decomposition of preciously living organisms such as plants and animals and their waste products. Sources of organic material for anaerobic digestion include dairy manure, food processing waste, plants residues and other organic wastes such as municipal waste water, food waste, fats, oils and grease. The manures of livestock can also be used which helps in reduction of greenhouse gas emission and odor.

The product is composed typically of methane and carbon dioxide and small amounts of H_2S and traces of other gases. The biogas can be burnt to generate heat and power or can be processed into gas or liquid fuel. The solid digestate can be composted and used for dairy bedding and as soil mixes. The digested liquid can be used as natural fertilizers.

The benefits of anaerobic digestion apart from generating energy includes: reduction in greenhouse gas emission, better air quality due to reduced odor, improved ground water quality as the pathogen activity is reduced, reduced fertilizer & bedding cost.

B. Anaerobic Digestion Process

Anaerobic digestion process consists of four steps.

1) Hydrolysis

2) Acidogenesis
3) Acetogenesis
4) Methanogenesis

- Hydrolysis: In hydrolysis, the complex organic compounds are decomposed into simple soluble monomers. Proteins into amino acids, lipids into fatty acids, starch into glucose and carbohydrates into sugar.
- Acidogenesis: This is the fastest step among the four and the simpler monomers from hydrolysis are decomposed by fermentative bacteria (acidogens) into a mixture of volatile fatty acids (VFA).
- Acetogenesis: The volatile fatty acids are further converted into acetate, CO_2 and hydrogen by the acetogenic bacteria.
- Methanogenesis: This is the final step where the substrate from the previous stage is converted into methane and carbon dioxide.

C. Influencing Parameters

This section discuss on the factors influencing the decomposition of the organic compounds into methane.

- Feedstock characteristics
- Operating temperature
- pH
- Retention time
- C/N

1) Feedstock Characteristics

Any organic substance can be used as a feedstock. It ranges from agricultural waste, food waste, vegetable waste, dairy waste, effluent from factory or process plant and livestock manure. The primary characteristics include the moisture content, total solids, volatile solids, pH, particle size and carbon to nitrogen ratio. Higher concentration of VFA and ammonia stops the process from happening by altering bacteria population. The process entirely depends on consistent bacterial population during each step.

2) Temperature

Temperature is the most critical parameter affecting the entire process of methane formation by bacterial activity. Anaerobic digestion occurs at three temperature ranges.

- Thermophylic process (50^oC - 60^oC)
- Measophylic process (35^oC - 45^oC)
- Psychrophylic process (15^oC - 25^oC)

It is very essential to maintain the temperature steady inside the digester throughout. Studies show that a even 5 to 10^OC fluctuation inside the digester can reduce the gas yield by 50%. Digestion completely stops when the temperature goes below 15^OC.

3) pH

4) Retention time

The average time the feedstock stays inside the digester space is known as retention time. Solid retention time and hydraulic retention time are the two terms used. The retention time is longer if the digester operates at lower temperature range. Literature shows that, the retention time is 3-5 days when the digester operates at thermophylic range. It takes 10-15 days for mesophylic range and even longer when it operates at psychrophylic range.

5) C/N

Carbon to Nitrogen ratio also influences the yield of biogas during anaerobic digestion. A C/N ratio of around 30 is desirable. Low C/N means, more total ammonia nitrogen (TAN) and VFAs inside the digester. TAN and VFA beyond a limit inhibit the methanogenesis process.

II. LITERATURE REVIEW

The anaerobic digester systems could be of Batch type or Continuous type. The batch type digester was loaded once for certain time period for complete digestion and the Continuous type digester was loaded at a constant rate and a constant pH and C/N ratio are maintained at the optimum level.

An experimental analysis of generation of biogas from kitchen waste was carried out with the comparison of biogas production using kitchen waste and cow dung. The kitchen waste and cow dung was taken in different proportions and the experiment was carried out. Then the measurement was done for each samples and analysed. The result concluded that the food waste samples were produced more biogas than the cow dung [1].

Bio-methane generation from organic waste on different substrates and methods of improving gas production was carried out in a detailed manner and it has been recommended that production can be enhanced by co digestion method. A comparison between batch type and a continuous type digester system was also [2].

The study of innovations in generation of Biogas from kitchen food waste and cow dung was carried out and it has been found that the production of biogas can be increased with increasing proportion of cow dung [3].

A study on biogas production from different kitchen waste carried out at varying operating temperatures from 25ºC to 36ºC and pH ranged from 5.5 to 8.5 with constant feed of kitchen waste. The substrates were analysed at regular intervals for the biogas production. This study concluded that food waste/ kitchen waste as a potential sources for generation of methane [4].

Effect of temperature and Hydraulic retention time of anaerobic digestion of food waste was carried out. It has been concluded that, Thermophylic digester gives a stable performance than a Measophylic digester as the bacterial activity is high at higher temperature [5].

Effect of carbon to nitrogen ratio of food waste on biogas production in a batch Measophylic anaerobic was carried out and it has been found that, yield and efficiency of gas production is higher when the C/N ratio is in the range of 26 to 30 [6].

A study with co digestion to increase gas production has been carried out. It has been revealed that co digestion can be adopted for feedstocks that are difficult to digest. The co digestion feed stock with optimum pH and C/N ratio can be chosen based on the availability and cost. Lower pH will increase the acidity and killing the methanogenesis bacteria that will eventually stop the gas formation. [7].

III. Experimental setup

The experimental trials were carried out with three different capacity digesters (containers) with different combination of feedstock. First trial was made with 8 liters capacity plastic containers.

A. Set up for Trial 1

The trial 1 setup has been carried out with the four different types of feed stocks. The feed stocks mentioned in the table were dumped in the 8 liter capacity containers and are connected with small tubes.

Fig. 1: Digester set up - Trial 1

Table - 2
Feed stocks

Container (a)	
Cooked Rice	*2 kg*
Vegetable wastes	*2 kg*
Cow dung	*2 kg*
Water	*8 liter*
Methylated spirit	*80 ml*
Container (b)	
Cooked Chicken	*2 kg*
Vegetable wastes	*2 kg*
Cow dung	*3 kg*
Water	*11liter*
Methylated spirit	*110 ml*

The hole made to insert the tube has been sealed perfectly to prevent air ingression. The containers were sealed perfectly using leukoplast. The containers were kept at room temperature in a closed space. After 7days the measurement was taken regularly for analyse the biogas production. In this setup each container had a free space of 1/3 of the total space of the container.

B. Set up for Trial 2

In this trial setup a 50liter capacity plastic drum was used as a digester. A ball valve was placed on the top of the digester drum and a quick fit connection was used to fasten a pneumatic hose. The other end of the hose was connected to a burner arrangement. The arrangement is shown in the following figure.

Table - 2
Feedstock combination for Trial set up 1

Container 1	
Cow dung	*500 g*
Water	*1litre*
Container 2	
Vegetable wastes	*300 g*
Cow dung	*50 g*
Water	*1 litre*
Methylated spirit	*50 ml*
Container 3	
Food waste	*1 kg*
Vegetable wastes	*50 g*
Cow dung	*150 g*
Water	*1 litre*
Methylated spirit	*20 ml*
Container 4	
Chicken waste (Cooked)	*300 g*
Cow dung	*150 g*
Water	*1 litre*
Methylated spirit	*20 ml*

(a) (b)
Fig. 2: Digester set up – Trial 2

The feedstock, vegetable waste in (a) and cooked chicken in (b) were crushed to smaller particles to enhance the anaerobic digestion process. The bones in the chicken waste were removed which otherwise would inhibit digestion process. Cow dung was used as Inoculum which enhances bacterial activity and speeds up gas formation.

C. Set up for Trial 3

In this setup 2 arrangement was done with each of a 20 Ltrs capacity drum. In this one setup was filled with 2 kg of vegetables, 1 kg of cow dung, 50 ml of Methylated spirit and 5 Ltr of water; and the another setup was filled with 2 kg of cooked chicken, 1 kg of cow dung, 50 ml of Methylated spirit and 5 Ltr of water. The top portion of the drum was closed with the help of a rubber cork and syringe was placed on the top of the rubber cork and it is sealed with the cork by the M-seal without any leakage. During the digestion process, the gas will be produced inside the digester tank and forces the plunger of the syringe upwards. The amount of plunger displaces shows the amount of gas produced inside the digester tank.

Fig. 3: Digester set up – Trial 3

Another method to measure the volume of gas produced is by water displacement method which is based on Archimedes principle. In this arrangement the digester tank is connected with a water displacement setup using a hose and a ball wall. A beaker is inserted upside down in th tub. The gas evolve from the digester will displace the water inside the beaker. Tha amount of water raised is proportional to the amount of gas evolved.

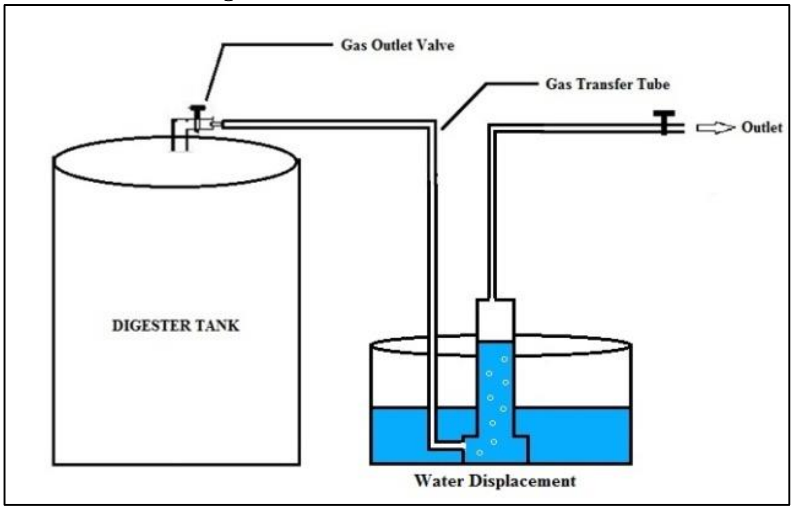

Fig. 4: Schematic of water displacement method

IV. Results and discussion

- Trial 1: In this trial setup, the 8L capacity containers were connected with flexible hoses. The end of the tube which is connected to the container was sealed perfectly to avoid air entering into it. The containers were kept isolated at room temperature. After a period of around 7days, the level of water displaced proven the gas formation.

  It has been observed that gas formed from all the feedstock with higher amount of gas production from cooked chicken followed by vegetables than cow dung. The gases formed where burnt by burning it passing it through a regulated burner setup.
- Trial 2: In this trial setup, two containers of 50 L capacity were used. One was stocked with cooked rice, vegetable wastes, cow dung, water and Methylated spirit. Cow dung is used as Inoculum with the 1:1 proportion of cow dung and water. After a period of 20 days, gas production commenced.

  In the second container, vegetable wastes, cooked chicken, cow dung and Methylated spirit were fed Here also, cow dung has been used as Inoculum with the 1:1 proportion of cow dung and water. The observation was made and as like the previous case, after a period of 18 to 20 days, gases start to evolve. The quantity of gas produced from cooked chicken was found to be higher compared to gas formation from vegetable wastes. In both the cases, the gas burnt with a blue flame.
- Trial 3: In this trial setup, two containers of 20 L capacity were used. This trail has been made to understand the effect of digester capacity on gas formation and retention time. One of the containers was stocked with vegetables, cow dung, Methylated spirit and water; and the second was filled with cooked chicken, cow dung, Methylated spirit and water. Both the containers were sealed with rubber cork with a syringe inserted into it. As in the previous case, the quantity of gas produced from cooked chicken was found to be higher compared to gas formation from vegetable wastes. The plunger moved 50 ml capacity with cooked chicken and 20 ml capacity with vegetable waste. In both the cases, the gas burnt with a blue flame.

  Apart from this, few rough trials were also made using various other feedstocks to check for gas formation. A trial was made with cooked rice and egg shells and another with cooked vegetables and bone remains of cooked meat and chicken. No or meagre amount of gas were found to be evolved due to the formation of ammonia which inhibits the bacterial activity and hence the methanogenesis process.

V. Conclusions

A fundamental study to understand the basic concepts of anaerobic digestion process for biogas formation was carried out. Few trials were made with different capacity digester and different types of feedstock. All these trials were carried out at atmospheric temperature. The major conclusion from this study includes that the gas production is enhanced by using cow dung as inoculums and methylated spirit. Among the feedstock used, gas production is more with cooked chicken followed by vegetable waste It has also been found that cooked rice with egg shells and or bones produce no biogas as ammonia production in this case inhibits the bacterial activity and in turn the methanogenesis process. In the future, a detailed quantitative study will be carried out to quantify the anaerobic digestion process.

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