Building a Functional Biogas Digestor

Contents

Gold Crest Award

BRITISH SCIENCE ASSOCIATION

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To whom this may concern,

This is to confirm that Ananth Krishna from Lakshmi School achieved the Gold CREST Award for the project, GO-0000009447, titled 'Building a functional prototype of a biogas plant,' on 09 September 2024.

This letter, with control number LCCA-00-00040, is being issued while the Gold CREST certificate is still in transit.

Regards,

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Aims

I attempted to construct a functional prototype of a plant that can generate biogas from a mixture of food waste and cow dung. Breaking this down further:

- Research available instructions to build a working biogas plant at home.

- Prepare a list of materials required to build this plant.
- Establish the success metrics of such a plant, i.e., burning steadily and payback calculations.
- Build the plant.
- Compare prototype with success metrics; analyse reasons for shortcomings, if any.
- Revise until plant meets success metrics.
- Analyse findings and calculate payback days.

Context and Background

The world has warmed by over 1°C from pre-industrial times, driven by humanity's emissions of greenhouse gases[i]. While carbon dioxide emission reduction has received a lot of attention, reduction in methane emissions has received far less attention[ii]. This, despite the fact that in 2021, methane accounted for over 17% of human emissions of greenhouse gases[iii]. The energy and waste sectors are major contributors to methane emissions[iv]. To learn how individuals might reduce their carbon footprint, I wanted to build a biogas plant at home. While we already had a larger biogas plant at home, it was not "off-the-shelf" and was too large (occupied five square metres) for most homes. Furthermore, the manufacturer had gone out of business, so if the plant failed, there was no way to repair it. However, it served as a starting point for my investigation, and I began to monitor its operations.

The plant served three purposes. Initially, it allowed us to transform all of our kitchen waste (including leftover food and peel fragments) weighing between 1.5-3 kilogramme per day into biogas. By doing this, we successfully diverted our food waste from being going to a landfill, thus mitigating the release of greenhouse gas emissions, particularly methane. Additionally, it helped in reducing our LPG (Liquefied petroleum gas) use for cooking. An examination of our LPG gas cylinder purchases showed that we saved half a cylinder a month (1 cylinder= 14.2 kilogrammes) thanks to this plant. Last but not least, the plant's waste, leachate (slurry), enhanced the soil's fertility in our garden. Still, this biogas plant suffered from some challenges, including:

- The plant choked when certain types of food (oil) or when larger pieces of food waste were put into the plant.
- Occasionally, the plant emitted a foul odour for no easily-observable reason.
- The plant could not be bought off-the-shelf, and if it broke down, we could not repair it at home.

My earlier research on an allied topic i.e. ' Hydrogen Production from waste water using micro-organisms' was published in NHSJS in 2024, gave me a sound theoretical knowledge on how microorganisms break down organic matter and what criterion were important to improve the efficiency of gas generation. I will elaborate this in the following paragraph. While I did analyse other instructional videos on how to build small biogas plants, I believed only building a plant would give me a better insight into what practically worked and what did not in a biogas plant. I therefore decided to construct a prototype biogas plant that addressed some of the shortcomings of our existing plant.

Biogas is composed by a mixture of 50–75% methane, 25–50% carbon dioxide, and 2–8% other gases (nitrogen, oxygen, hydrogen sulphide, among others). The percentage of methane in the biogas mixture determines its suitability for use as an energy source; this also depends on the substrate that is usedv. Biogas is formed when microorganisms (bacteria) break down organic matter in an oxygen-free environment by a process called bio-methanation. It occurs in four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis[vi]. The first step (hydrolysis) involves hydrolysing complex compounds such as proteins, carbohydrates and lipids into sugars, amino acids and fatty acids by extracellular enzyme (cellulase, amylase, protease or lipase) as soluble organic molecules. Next in acidogenesis, the soluble organic molecules from the earlier step are used by fermentative bacteria to produce volatile fatty acids (acetic acid, propionic acid and butyric acid), alcohols, aldehydes, along with carbon dioxide, hydrogen and ammonia.

Thirdly in acetogenesis, the acidification produced products are converted by acetogenic bacteria into acetic acids, hydrogen, and carbon dioxide. Finally, in methanogenesis, methanogens in the slurry convert acids into acetate and hydrogen into methane.

The reaction is governed by various factors, primarily temperature, pH, HRT (Hydraulic retention time) and OLR (organic loading rate, or how much food we put in at a given time). Firstly, a temperature range of 32-35 °C is optimum for stable and efficient biogas production. That's because the microbes of interest in this process are the most active around mesophilic (25-45°C) and thermophilic conditions (45-70°C). A pH between 6.8-7.2 is optimum for production of methane, which can be maintained by an optimum OLR. As the process proceeds, the acidity of the medium increases and this can be counteracted by adding lime to the mixture. The pH is critical as it impedes the growth of methanogenic organisms and how quickly organic compounds are broken down to produce methane. OLR is the measure of how much food is loaded in the reactor per unit volume (of the reactor) per unit time. A greater OLR will result in a greater yield, due to better digestion of the substrate. HRT is the average time for which the substrate remains inside the reactor before leaving it, and a longer HRT is correlated with higher gas percentage in the reactor and gas yield (Mamun et al., 2015). My goal was to optimise these parameters in my prototype. While it is difficult to precisely control these parameters in a home-built biogas plant, the following precautions were taken: The biogas reactor was stored in a closed, dry environment to minimize the influence of external temperature. For the most part, the temperature around the reactor was kept at 35 +/- 10°C. The pH was controlled by adding fresh feedstock to the reactor at regular intervals, to dilute the volatile acids produced in the reactor. Further, the feedstock itself was diluted with water in a 1:2 ratio by volume (organic content: water) to improve efficiency by reducing inhibition of reaction by organic acids. OLR and HRT are related: simply put, if one feeds more, we have to give it the microbes more time to digest it.

Elements of the Biogas plant and function

A typical biogas plant has the following parts[vii]:

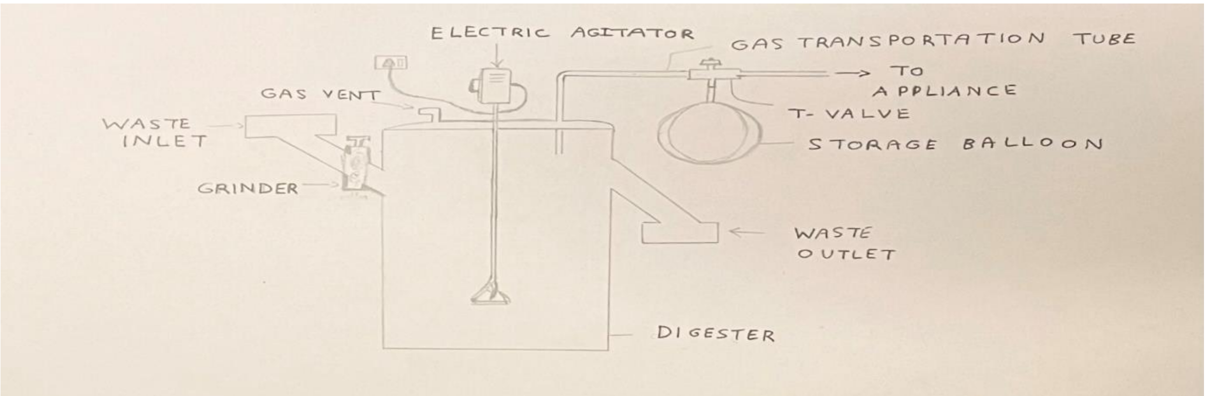

Figure 1: Schematic of Biogas plant

(Details can be shared on request)

Prototype 1 & 2

By February 2024, the feature set (with detailed specifications) of the biogas plant was compiled. In February, when building the first prototype, Prototype 1, I sought the assistance from the lead researcher of Sundaram Climate Institute (SCI, where I am pursuing a part term internship) for buying material and in building the plant. Based on her suggestion, I gave the specification to a local shop to build the plant.

Figure 2: Prototype 1

Once the digester was built, I shifted my attention to the feedstock. As highlighted earlier, the chosen feedstock was a combination of peel waste (vegetable/fruit peels) and leftover food ground in a household blender. However, the breakdown of this food waste into methane necessitates the presence of high concentrations of methanogenic bacteria in order to produce the desired levels of methane. These bacteria are abundantly found in cow dung[viii]. I therefore went to a cow shed near my home and convinced the owner of the shed to provide me with some cow dung. He agreed to do so free of cost and I used this dung diluted 1:1 with water to grow the bacterial culture in the digester. My research (Mamun et al., 2015) suggested gas formation in the biogas digester was a gradual process and peaked at 4 to 5 days after dung was loaded into the digester. Therefore, five days after the feedstock was introduced into the digester, I visually checked the inflation of a rubber balloon linked to the outlet pipe to see if gas was being produced.

Given the nature of the construction, it was not possible to check if the agitator was working as it should – ensuring an even mixing of feedstock and the microbes from the slurry, and modulating temperature and ph. Even after a month had passed after feeding the prototype, the rubber balloon failed to inflate. I checked the plant for stability and leaks. The visual inspection method was used to check for presence of cracks, if any. I also drove compressed air from a pump through the prototype after spreading soap solution all around its exterior. Two cracks were seen in the reactor and dome, and these were rectified. Three small leaks were observed in the pipe that carried gas away from the plant and these were sealed. The plant was refed with feedstock of crushed food waste, and cow dung slurry was used to catalyse bacterial culture formation. There was no gas build up in the reactor, since the storage balloon was empty and further no flame was observed when the gas inside the plant was burnt.

I decided to try a new build. This time, in March 2024, while I gave the list of material to the SCI researcher for purchase, I built the plant myself with the help of a local carpenter. Building the plant, rather than evaluating one that could be made to my specifications, helped me to understand any points/sources of weaknesses during assembly and counteracting those at the construction phase itself to get a robust plant. The construction of the prototype could be accelerated this time because of the learnings from the previous iteration. We kept the digester transparent to see if the level of feedstock was falling, but to keep the digester dark, placed it inside a cardboard box within a dark room.

Figure 3: Prototype Plant 2

To assure bacterial development, this plant was once more fed with cow dung slurry. After five days, I observed that there was no gas build up in the plant. While checking for leaks, I identified a small leak in the waste inlet tube as the probable cause. The leak was sealed, and the plant design was modified whereby a PVC cap was fitted onto the inlet tube (to prevent air entry or gas escape) and all tubes were re-sealed. The plant was then fed again with slurry. After five days, a small gas buildup could be seen. Although the balloon did not inflate, a rudimentary flame test – placing a lit match at the outlet of the outgoing gas pipe and seeing if the flame became larger when the outlet was opened –confirmed the presence of methane. After a week, when gas generation did not improve (balloon did not inflate), I realised that I did not possess the instruments to check the methane percentage in the output gas, which made it difficult to understand how my design had to be modified to make it work. Yes, the gas was being generated, but was the low flame because of poor gas generation or low methane content. Without the methane measurement, there was no way to move forward.

Prototype 3

Carbon Masters (www.carbonmasters.co.uk) is a company that has expertise in this subject. They loaned me an instrument to measure the methane in the storage ballon, which told me that 16% of the gas produced in the storage balloon was methane. I requested for an internship with Carbon Masters in Bengaluru to develop the next version of the biogas plant. Further, the company had a lab and all testing instruments available in-house, which meant that I could quickly measure the operating parameters of my prototype.

In May 2024, after my exams, I travelled to Bengaluru and began my work as a biogas system design intern under the guidance of a Carbon Masters employee. Before building another prototype, I visited the site of the bigas plant that was operated by Carbon Masters at Koramangala, Bengaluru, which gave me a better understanding of what is required in a running biogas plant. The design of the third biogas plant prototype was finalised.

This time, I procured all the parts required on my own since I wanted to avoid issues such as cracks and leaks in any of the bought materials.

Figure 4: Prototype Plant 3

The assembly of the plant was completed within a few days (due to learnings from building earlier prototypes). The steps taken to construct this are laid out in Appendix 5. The plant was fed with working culture from the biogas plant I visited. In the three days it took for the bacterial culture to establish and the reaction to stabilise, I visited a larger biogas plant (capacity of 150 cubic metres) and conducted research around safety issues in biogas plant operation and compiled a report of known accidents in biogas plants and their root causes (attached in Appendix 1). Using my previous learnings in building two prototypes and my earlier research on the subject, I was able to assist the Carbon Masters team in solving technical issues related to foaming in the plant digester and odour control (see Appendix 2). Both of these reports helped me develop a deeper understanding of biogas plant functioning. Since structural weaknesses in gas pipelines was identified as the lead cause of accidents in biogas plants, I researched the topic and compiled a note on best practices surrounding design of pipelines (see issue 3, Appendix 2). Finally, I analysed my prototype plant for gas build up, and measured the identification of gas build up. The gas from my prototype had 25% methane content on the 3rd day after the feedstock was fed and this percentage rose to 40% on the 5th day, which was sufficient to light in a stove. The biogas generated has a methane content of approximately 40%.[1]

Methane Content in Prototypes

Prototype/Day	Methane %
Prototype 2 – Day 6[2]	16%
Prototype 3 – Day 3	25%
Prototype 3 – Day 5	40%

The methane content was measured using a machine called a portable biogas analyser, which can be plugged into the gas outlet system and displays the gas content of the gas being generated (see below). Since the machine was in regular use (and calibration) by the Carbon Master's team, I did not further calibrate it.

[1] My guide in Carbon Masters told me that a 40% methane content was necessary to make biogas burn in a kitchen stove.
[2] Prototype 2: First feeding, waited 7 days, no flame. Refed, waiting 7 more days, small flame. Refed, and sent to Bengaluru for testing. Six days after the third feeding this result was obtained.

Figure 5: Illustrative Portable Biogas Analyser.

Conclusions

I was able to build a working biogas prototype from off-the-shelf items in my third attempt, meeting the aims of my project. The payback calculations (see Appendix 3 for details) showed that the costs incurred could be recovered in less than six years based on the benefit of LPG saved.

(Further details can be shared on request)

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[i] Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., Trisos, C., Romero, J., Aldunce, P., Barret, K. and Blanco, G., 2023. IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

[ii] Ibid.

[iii] Climate Watch. 2024. Washington, DC: World Resources Institute. Available online at: https://www.climatewatchdata.org.

[iv] Ibid.

[v] 'Biogas Power Energy Production From a Life Cycle Thinking', Enrique Alberto Huerta-Reynoso, Hector Alfredo López-Aguilar, Jorge Alberto Gómez, María Guadalupe Gómez-Méndez and Antonino Pérez-Hernández, 01-Feb-2019. https://www.intechopen.com/chapters/64678

[vi] Al Mamun, M. R., & Torii, S. (2015). Enhancement of production and upgradation of biogas using different techniques-a review. *International Journal of Earth Sciences and Engineering*, *8*(2), 877-892

[vii] 'Small-Size Biogas Technology Applications for Rural Areas in the Context of Developing Countries', Martina Pilloni and Tareq Abu Hamed, 24-Mar-2021, https://www.intechopen.com/chapters/75926

[viii] 'Small-Size Biogas Technology Applications for Rural Areas in the Context of Developing Countries', Martina Pilloni and Tareq Abu Hamed, 24-Mar-2021, https://www.intechopen.com/chapters/75926