JOURNAL OF
EMERGING INVESTIGATORS

Article

Maximizing anaerobic biogas production using temperature variance

Kushagra Verma[1]*, Utkarsh Sharma[2]*, Suruchi Agrawal[2]
[1]Ridge High School, Basking Ridge, New Jersey.
[2]Amity International School, Vasundhara, Uttar Pradesh, India.
*Authors contributed equally.

SUMMARY

We conducted this research as our start-up's research that addresses the problem of biogas production in cow-dense regions like India. We wanted to evaluate variables which would enable us to increase biogas production and ultimately increase the efficiency of our system. Through our prior knowledge of anaerobic digestion, we knew that temperature could be used as a variable to collect distinct data points and pursue our research. We hypothesized that the thermophilic temperature (45-60°C) would increase biogas production. This phenomenon happens primarily because, at this range, Methanobacteria (responsible for producing methane from slurry) multiply and digest the slurry (mixture of cow dung and water) at an optimum rate. Mesophilic temperature (<45°C) doesn't yield this optimum growth rate. Hence, the production process is much faster and more abundant at temperatures around 55-60°C. Our methods included trapping biogas produced inside a tire and measuring the change in the tire's mass to predict the quantity of biogas produced. We measured the gas production in grams for the ease of experimenting using the available apparatus. Through our experiment, we concluded that this difference in production was almost two-fold. At mesophilic temperature, 121 g of biogas was produced in 15 days. At thermophilic temperature, the biogas production was about 247 g in the same period.

INTRODUCTION

Despite accounting for the world's largest cattle and human population, India has notably underperformed in the biogas sector (1). This is due to two significant inefficiencies: supply chain inefficiency and the lack of proper "know-how" for converting waste to biogas on a macro-level (2). The reasons for this lie behind the industry being largely unorganized and run by scattered and non-technical cow-bearing individuals/dairy farmers (10-15 cows) within their homes on a very micro scale (2). In short, there needs to be more proper commercialization of the process. Therefore, by creating a decentralized energy system to connect multiple stakeholders – dairy farmers, biogas plant owners, and logistics – India could venture into this highly underutilized market to create value for society and bolster its efforts to fight for a greener future.

Despite all the technical advances toward sustainable energy, the world still relies on nonrenewable energy sources to meet 80 % of its demands (3). Undoubtedly, biogas is one of the slowest-growing renewable energy sectors (3). Biogas is an efficient fuel since it has a caloric value of roughly 25 MJ/m^3 (subject to the quality of cow dung and the anaerobic digestion process) (4). Biogas has numerous use cases: producing electricity, processing it into bio-compressed natural gas (CNG), and usage as cooking fuel (4). Explicitly focusing on cow dung, the organic matter contained in it can be transformed into desired energy resources through anaerobic digestion (4). For this process, manure is mixed with water in variable ratio and kept in an anaerobic digester.

Anaerobic digestion is the breakdown of organic material by bacteria in the absence of oxygen. This process employs hydrolytic, acidogenic, and methanogenic bacteria to break down complex organic material into biogas molecules. This process yields two major biproducts: biogas and manure. Thus, biogas can be derived from cow dung. Biogas is a mixture of methane (a majority percent), carbon dioxide, and hydrogen sulfide (5). In our study, we wanted to test whether a temperature difference would play a role in bacterial growth and activity during anaerobic digestion of cow dung, and thus affect the amount of biogas produced. Therefore, we proceeded with our research by keeping temperature difference as a variant. We have employed Ideal Gas Law to interpret our results. The Ideal Gas Law is one of the fundamental laws of physical chemistry that helps us relate different variables of an ideal gas, which is just a gas whose molecules do not interact with each other and occupy negligible space.

RESULTS

Our experiments involved adding a mixture of cow dung and water into a closed tank that decomposed the contents

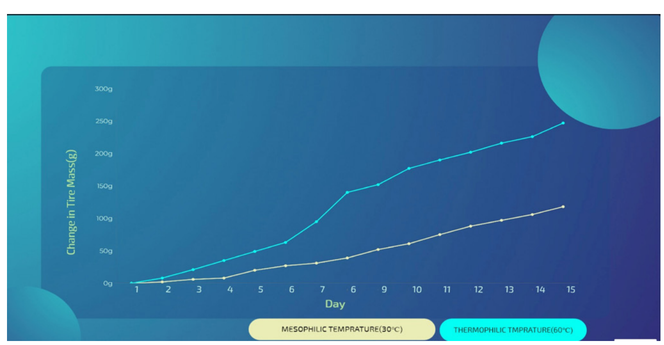

Figure 1: Daily Biogas Production. Biomethane production at mesophilic (30°C) and thermophilic (60°C) temperatures. At thermophilic temperature the gas production is twice of that produced at mesophilic temperature (based upon 15-day average).

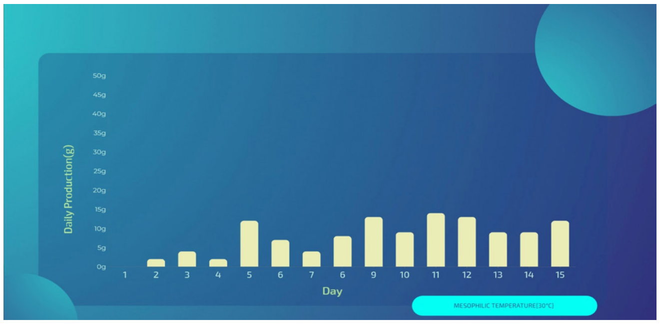

Figure 2: Average daily gas production at mesophilic temperature (30°C). Bar graph shows that the average daily biogas production is 8.57 grams, whereas the standard deviation is 4.39 grams (based upon 15-day average).

to produce biogas without air. Although the gases produced (mostly methane) do not behave like ideal gases since the molecules interact with each other and occupy some space, for the sake of estimating the amount of biogas produced, we used the Ideal Gas Law. The produced biogas inflated the tire, and we measured the change in the tire's mass to predict the amount of biogas produced. We then used the Ideal Gas Law, which states that under constant temperature and volume, the number of moles of a gas (or simply the mass of the gas) is directly proportional to the pressure exerted. Since the pressure exerted on the tire increased and the tire's mass increased, we concluded that the amount of gas increased in the tires.

If we compare the graphs of the two plotted lines (**Figure 1**), the thermophilic line has a steeper slope. Thus, we can conclude the thermophilic temperature leads to biogas production at a higher rate. Biogas production in experiment 2 (thermophilic) was roughly twice when compared to the amount of biogas produced in experiment 1 (mesophilic). Since the starting mass of raw material fed in the two experiments was around (3 kg), we can say that:

A. At a mesophilic temperature, 1 kg of 1:1 ratio slurry produced 0.0403 kgs of biogas (4.03 % conversion rate).
B. At a higher thermophilic temperature, 1 kg of 1:1 ratio slurry produced 0.0823 kgs of biogas (8.23 % conversion rate).

By comparing the daily biogas production in the tire (**Figure 2 and Figure 3**), we can conclude that at thermophilic temperature the biogas production peaked by the end of the first week. These results also suggest that biogas production reaches its peak rate around the 5th-7th day of anaerobic digestion at thermophilic temperature.

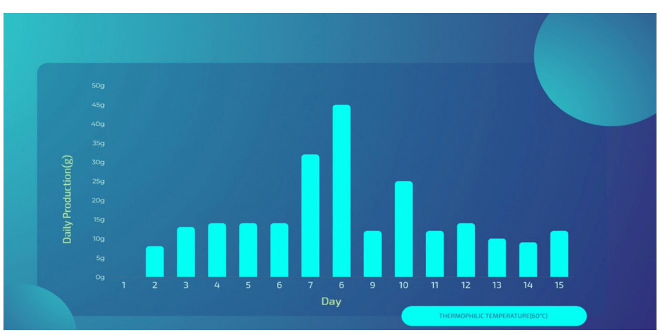

Figure 3: Average daily gas production at thermophilic temperature (60°C). Bar graph shows that the average daily biogas production is 17.57 grams, whereas the standard deviation is 9.31 grams.

DISCUSSION

As we saw in our results, a higher temperature increased the amount of biogas produced. This conclusion was a point of guidance for our biogas plant's design because even a slight increase in production can be very beneficial. One factor that could have limited our experiment was the escape of gases; however, by sealing the tank and tire, we limited the likelihood of gas escaping. Since there was no precise mechanism to sense any leaking gas, we expect some error in our observations, and performing replicate experiments can address this issue.

We want to further experiment with production output using cow dung from various breeds. This will provide additional data to determine the most suitable breed of cow dung for anaerobic digestion, which can produce hybrid offspring in geographically favorable areas to enhance biogas production. The type of fodder given to cows can be yet another factor that will provide us with a better understanding of the effect of fodder on the amount of biogas produced from the cow's dung. We employed an equal ratio of water and cow dung as an instinctive approach. However, this factor can be further investigated using a pH meter and a variance in the ratios to analyze the suitable pH levels required to maximize biogas potential.

For the issue of oxygen, which pre-exists in the biodigester, it does not affect the net effectiveness of the biogas production, as its concentration is low and the digester is sealed; hence, fresh air doesn't enter the digestor. Moreover, this limited amount of oxygen also helps remove hydrogen sulfide from the biogas, as removal of hydrogen sulfide require a higher optimum concentration of oxygen to enable absorption of hydrogen sulfide using iron oxide, which further helps increase the digester's longevity and improve the quality of gas produced (6).

The implications of biogas as a resource are important. Cow waste and human waste are wastes that need management and with proper supply chains, we can solve the issue of waste management and produce energy from a shallow resource utility. In monetary terms, the energy and bio manure production from human and cow waste could amount to $100 billion (speculative figure based upon cattle population in India and economic value of gas production per cattle) if we could effectively handle the supply chain problems of different stakeholders involved in this domain (2).

Another interesting perspective of looking at the heated digester could be to find the total energy produced, which would be the difference between energy obtained and energy spent heating the system. Generally, energy is produced using this gas with the help of generators, which typically operate at an efficiency rate of about 60 %-70 %. In this case, the digester can use the 40 %-30 % energy dissipated as heat to heat itself, utilizing a heat exchanger system.

As stated before, one of the critical implications of a higher temperature might be due to an increase in bacterial activity and growth, which leads to the production of biogas. The optimum temperature might differ based on different qualities of slurry (depending on the type of cow), as the quality of cow

Figure 4: Digestion chamber attached with the gas collection tube. The gas collection tube is attached with the digestion chamber via an airtight pressure valve.

dung is bound to differ in that case, resulting in a variance in bacterial reaction to the anaerobic digestion's stimuli.

This research helped us bolster our view of biogas production and its efficiency. It supported our hypothesis that a higher temperature would lead to a more significant breakdown of organic matter by bacteria in the absence of oxygen, boosting biogas production. From a broader perspective, this could lead to more effective waste management and could resolve the highly problematic issue of greenhouse gas emissions. Apart from the positive impact on the environment, higher gas production will also help increase the income of dairy farmers significantly and provide them with an alternative source of income for their livestock holdings. The decentralized system would in turn incentivize the agricultural workforce to become a part of this cyclic energy production process and develop the socioeconomic status of such regions on the backdrop of renewable energy.

Figure 5: Waste digestion setup in a temperature-controlled water-bath. The digestion system is placed in a water bath maintaining a temperature of 60^{O} using a thermostat along with a 250 W heating rod.

MATERIALS AND METHODS

We created slurry (cow dung and water mixed) using a 1:1 ratio by mass by combining the two materials. The slurry was added to a closed tank and sealed with a sealant. The tank had an opening to which a tube connected it to a tire (**Figure 4**). We attached a valve to the tube to control the biogas flow to the tire. To test the conditions favorable for anaerobic digestion, we had to create a temperature difference between the two settings. Since the temperature requirements for the two experiments were 25^{O}C and 60^{O}C, we maintained the former temperature by keeping our tank of slurry at room temperature. For the second experiment (**Figure 5**), we used an immersion rod to heat the water, a water bath to warm the tank, and a thermostat to prevent the temperature in the water bath from rising beyond 60^{O}C. Each day we tested the change in mass of the tire to predict the amount of biogas produced from the tank as the volume of the tank remained constant, and as gas inflated the tire, the mass of the tire increased.

ACKNOWLEDGEMENTS

The authors would like to convey heartfelt gratitude to Mrs. Daizy Arora for their tremendous mentorship and support in completing this research project. We would also like to thank Mrs. Bhavna Kulshrestha, Principal of Amity International School for supporting the development of this research project.

Received: August 24, 2022
Accepted: January 2, 2023
Published: August 3, 2023

REFERENCES

1. "Vizion Z Project Website." Vizion Z Renewables. www.vizionz.nicepage.io/vizion-z.html?version=b73d67be-5499-4744-a4ac-a28b1c9ac633. Accessed 1 May 2021.
2. "Vizion Z renewables." Entrepreneurship Campu s. www.entrepreneurship-campus.org/ideas/30/19899. Accessed 1 May 2021.
3. "Global Bioenergy Statistics 2019." World Bioenergy Association. www.worldbioenergy.org/uploads/191129%20WBA%20GBS%202019_HQ.pdf. Accessed 1 May 2021.
4. "An introduction to biogas and biomethane." International Energy Agency. www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane . Accessed 1 May 2021.
5. "How Does Anaerobic Digestion Work?" Environmental Protection Agency. www.epa.gov/agstar/how-does-anaerobic-digestion-work. Accessed 1 May 2021
6. "How Do You Remove H2S From Biogas?" Interra Global. www.interraglobal.com/how-do-you-remove-2s-from-biogas. Accessed 1 May 2021

Copyright: © 2023 Verma, Sharma, and Suruchi Agrawal. All JEI articles are distributed under the attribution non-commercial, no derivative license (http://creativecommons.org/licenses/by-nc-nd/3.0/). This means that anyone is free to share, copy and distribute an unaltered article for non-commercial purposes provided the original author and source is credited.