https://doi.org/10.31436/iiumecp.v1i1.3007

PROFILING ANAEROBIC DIGESTION STAGES FROM CAFETERIA FOOD WASTE FOR PRODUCTION OF BIOGAS

MARIATUL FADZILLAH MANSOR*, AHMAD IMAN IKMAL ADANAN, HUSNA AHMAD TAJUDDIN, AZLIN SUHAIDA AZMI

Department of Chemical Engineering and Sustainability, Kulliyyah of Engineering International Islamic University. Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia

**Corresponding author: mariatulf@iium.edu.my*

ABSTRACT: Population growth in Malaysia has led to a rise in waste production. Soon, the capacity of the sanitary landfill will not be sufficient to accommodate the daily garbage production. Therefore, biogas plants are one of the finest answers to this issue. There has been numerous research on the use of food waste (FW) to make biogas, which can then be transformed into renewable energy. Food waste constitutes the largest percentage of municipal solid waste in Malaysia (MSW). In this study, the acclimatization process was conducted to profile the stages in this process for 27 days using cafeteria food waste (CFW) as a substrate. During the process, the pH sample and biogas production was recorded. The results showed that the hydrolysis stage occurred during day 0-1, indicated by a drop in pH from 7 to 2. This was followed by the acidogenesis stage from day 2-14, with the pH remaining within the acidic range of 3.5-6.5. The acetogenesis stage took place from day 15-18, maintaining a similar acidic pH range. Lastly, the methanogenesis stage occurred during day 19-27, characterized by a significant increase in biogas production. Methanogenic archaea converted the produced acetate, hydrogen, and carbon dioxide into methane gas. Different total solid (TS) contents of CFW: 10%, 15%, and 20%, were investigated. The highest biogas production was observed with a TS content of 20%, resulting in an accumulated biogas volume of 360 ml over seven days of fermentation. Conversely, the lowest biogas production was observed with a TS content of 10%, yielding a biogas volume of 170 ml. This study demonstrates that biogas production increases with higher total solids (TS) content. Finally, this study proves that food waste is a potential feedstock for biogas production that can help to reduce the current issues of waste disposal.

KEYWORDS: *Profiling, Anaerobic Digestion, Cafeteria Food Waste, Biogas.*

1. INTRODUCTION

World populations are rising up to 64 million in 2022 [1]. The massive growth in population has a tremendous effect on natural resources. As the global population increases, the management of solid waste has become a burden for global economies and the need for more energy consumption increases. Renewable and non-renewable energy are the two types of energy that can be classified. Non-renewable energy refers to a natural resource that does not regenerate while renewable energy is obtained from ongoing replenishment through natural processes [2]. Renewable energy obtains all its different forms directly from the sun, wind, rain, ocean tides and biomass. Due to its vast access and capacity to be produced as a byproduct of numerous industrial and agricultural activities, biomass is a renewable energy source that is expanding and has a high development potential [3].

https://doi.org/10.31436/iiumecp.v1i1.3007

Biomass can be derived from forestry crops and leftovers, industrial residues, animal residues, municipal solid waste, and sewage. As of 2013, the largest share of municipal solid waste (MSW) produced in Malaysia is food waste (FW) [4]. Many nations are becoming worried about the amount of food that is wasted globally. The challenges are the annual production of FW and the quantity of food consumed. As food consumption increases, so will FW. Landfill is the primary waste disposal method in Malaysia with up to 80% utilization [5]. In addition to depleting valuable land, landfilling pollutes the air, water, and soil by releasing chemicals, pesticides, and methane into the soil, groundwater, and atmosphere. Biogenic matter, which includes all sorts of biomasses, decomposes into biogas under anaerobic circumstances.

Biogas typically refers to a gas generated by the biological breakdown of organic matter in lacking oxygen [6]. The major component of this naturally occurring biogas, methane, escapes into the atmosphere and significantly contributes to global warming. Due to the enormous environmental and financial advantages it provides, anaerobic digestion (AD) of food waste has drawn attention from all over the world. Digestion is indeed based on a reduction process consisting of a few biochemical events occurring in anoxic settings, which is why anaerobic digestion is frequently thought of as a complex process [7].

Anaerobic digestion produces methane through four distinct processes: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. By profiling each stage of acclimatization process for AD, we can understand the dynamics of microbial populations and their role in the degradation of FW. Production of biogas requires anaerobic digestion to be limited to one of the crucial factors such as total solid (TS) content of the food waste. The TS content of a sample is the mass of solids remaining after a sample has been dried divided by the original mass of the sample. Previous studies showed that the high-solids system was found to produce more methane production rate but there is also a study that found out the total methane production decreased with total solid (TS) content increasing from 10% to 25% [8]. Thus, this study was concentrated on profiling anaerobic digestion stages of cafeteria food waste for production of biogas. Furthermore, the TS content was also optimized to increase biogas production.

2. MATERIALS AND METHODS

Cafeteria food waste (CFW) used as a substrate was collected from Mahallah Faruq Cafeteria in IIUM Gombak campus. It consisted of leftover foods such as vegetables, meats, fish, rice, fruits, and sauces. The source of mixed culture sludge (MCS) used as inoculum in this experiment was Palm Oil Effluent (POME) collected from Biogas Plant in Pahang.

2.1. Sample Preparation

A food blender was used to homogenize the cafeteria food waste (CFW) into particles that are smaller than 2 mm in diameter. The CFW was blended with distilled water with the ratio of (4 g:1 ml) (CFW: distilled water). Prior to usage, the blended CFW was stored in a refrigerator at 4°C. The CFW was further diluted again with the same proportion of (4 g:1 ml) (CFW: distilled water) before being used in the experiment.

Three different samples were prepared in this project. The three samples differ in terms of total solid (TS) content of the cafeteria food waste (CFW). The sample preparation for each content is shown in Table 1.

Table 1: Sample preparation of each total solid (TS) content

TS content (%)	Ratio (CFW: Distilled Water)
20	20 g:100 ml
15	15 g:100 ml
10	10 g: 100 ml

2.2 Acclimatization of Mixed Culture Sludge

The modified Schott bottle with a working volume of 1000 ml was used as a reactor. In this study, the total volume in the reactor was at proportion (50:50) (CFW: MCS). The initial pH of the mixture was adjusted to pH 7. The daily production of biogas and the pH of the mixture was recorded for twenty-seven days. Besides, this seed was used as an inoculum for anaerobic digestion (AD) process.

2.3 Optimization Total Solid Content

For this experiment, 100 ml of acclimatization sample was added into 100 ml of the sample with TS content of 20%. The biogas production and pH were recorded for 7 days. Total carbohydrates of the samples were also analyzed. This step was repeated for TS content of 15% and 10%. Previous studies [8] and practical experiences have shown that anaerobic digestion tends to exhibit favorable performance within the 10-20% TS content range.

3. RESULTS AND DISCUSSION

3.1 Acclimatization of Mixed Culture Sludge

The cumulative biogas collected and pH value throughout the acclimatization process was plotted in Figure 1. From biogas produced, it can be indicated that from day 0-1 is considered as hydrolysis stage (S1) where the initial pH observed dropped from pH 7 to pH 2. The pH drop signifies the start of the acidogenesis stage in the acclimatization process. During hydrolysis stage, complex organic molecules in the substrate such as proteins, carbohydrates, and lipids are converted into smaller compounds such as sugars, amino acids, and fatty acids by hydrolysis bacteria.

Once hydrolysis occurs, the acidogenesis stage (S2) took place from day 2-14 where the pH of the substrate remains within the acidic pH range. The acidogenic bacteria take over and convert the simpler organic compounds produced in the hydrolysis stage into organic acids, alcohols, and other volatile fatty acids. During acidogenesis, pH decreases due to acidification, and VFAs accumulate. The production of VFAs is accompanied by the release of carbon dioxide and hydrogen gas, contributing to initial biogas production. However, biogas production during acidogenesis is relatively low compared to the later stages of acetogenesis and methanogenesis.

From day 15-18, with pH within the acidic range of 3.5-6.5, biogas production increases and further metabolizes the organic acids and volatile fatty acids produced in the acidogenesis stage (S3) into acetic acid, hydrogen and carbon dioxide. This stage is crucial for generating acetate, which is a key precursor for methane production in the next stage.

The final stage of the acclimatization process, which is methanogenesis (S4), occurred between day 19-27 where methanogenic archea converts the acetate, hydrogen and carbon dioxide into methane gas or biogas. This stage is marked by a significant increase in biogas production and low concentrations of VFAs can also be observed.

https://doi.org/10.31436/iiumecp.v1i1.3007

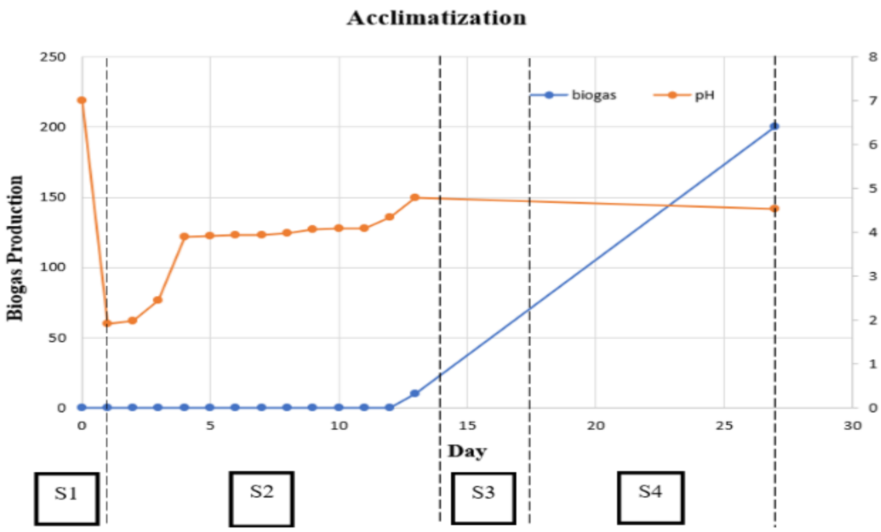

Figure 1: Biogas production and pH value for each stage in the acclimatization process

3.2 Optimization Total Solid Content

The accumulation of biogas in mL for different TS content of CFW was recorded as in Figure 2. The cumulative biogas produced by TS content of 20%, 15%, and 10% accounted to 360 ml, 250 ml, and 170 ml. Hence, biogas production showed an increasing trend with increasing TS content of CFW.

The acclimatization process aims to enhance biogas production in the anaerobic digester by ensuring efficient conversion of organic matter. This leads to higher biogas yields, stability, and sustainability. As a result, the cafeteria food waste (CFW) with 20% total solids (TS) content produced the highest biogas volume, as predicted by the initial total carbohydrates (TC) analysis. The results obtained were similar to previous study [8] in which substrates with higher TS content showed higher biogas production in the batch anaerobic digestion of CFW.

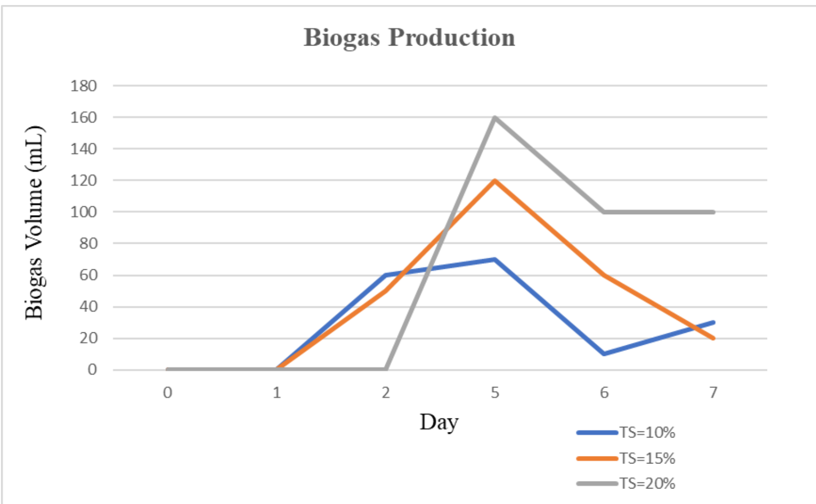

Figure 2: The cumulative biogas production for different (TS) content of CFW

https://doi.org/10.31436/iiumecp.v1i1.3007

It is well known that FW is a high degradable substrate for anaerobic digestion. For TS content of 5%, 10% and 20% at a fixed 7 days of solid retention time (SRT), increased TS content of CFW meant higher applied organic loading rate (OLR) and larger proportion of easily degradable substrate of microorganism, which results in higher volumetric biogas [10]. OLR indicates the quantity of organic material that is being fed into an anaerobic digester. High OLR can improve the processing efficiency of AD, while it might inhibit biogas production [11]. In this study, it is difficult to determine if the high OLR inhibited the biogas production, but the biogas produced showed an increasing trend with increasing TS content of CFW. So, it can conclude that high OLR in CFW improved the efficiency of AD process.

It is also clear that in Figure 2, the highest biogas production for all TS content was on day 5. It is difficult to point out a single factor affecting this, but one of the main factors is the peak concentration of carbohydrates just before day 5 of biogas production as shown in Figure 3. During anerobic digestion (AD), carbohydrates are significant components of organic matter that can be degraded by microorganisms. As the concentration of carbohydrates increases, there is typically more substrate available for microbial fermentation, leading to enhanced biogas production.

In the initial stages of anaerobic digestion, the total carbohydrates analysis value of food waste increases over time [12]. This rise occurs during hydrolysis and acidogenesis, where complex carbohydrates are broken down into sugars and fermented into volatile fatty acids (VFAs) like acetic acid, propionic acid, and butyric acid. These processes release soluble carbohydrates and VFAs into the digester, elevating the total carbohydrates analysis value. As digestion progresses, acetogenesis and methanogenesis take place. Acetogenic bacteria convert VFAs into acetic acid, hydrogen gas, and carbon dioxide, while methanogenic archaea utilize these compounds to produce methane gas. During acetogenesis and methanogenesis, some carbohydrates and VFAs are further broken down, resulting in a decrease in the total carbohydrates analysis value of the remaining digestate and higher biogas production.

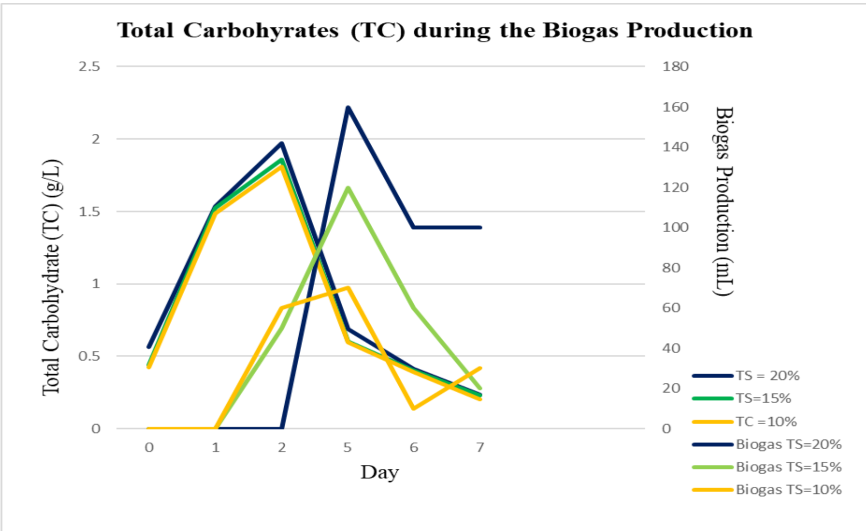

Figure 3: Total carbohydrate content during biogas production

Table 2 shows the pH values of substrates during AD. The average pH value for TS content of 20%, 15%, and 10% are 5.32, 5.31 and 5.30, respectively. These pH values were not within the optimal range for AD which is between pH 6.8- pH 7.4. This may be due to organic acid accumulation. During the AD process, organic acids are produced as intermediate products. If the digestion process is not well-balanced, the accumulation of organic acids can cause a drop in pH. This can occur if the SRT is too short. At low SRT, conversion of feedstock is limited, and organic acids are the main fermentation products [13].

Table 3: pH values of substrates for each TS during AD

Day	pH Value		
	TS = 20%	TS = 15%	TS = 10%
0	7.00	7.00	7.00
1	4.85	4.93	4.88
2	4.90	4.95	4.98
5	5.07	5.06	5.03
6	5.05	4.99	4.96
7	5.04	4.95	4.95

4. CONCLUSION

The AD of CFW was studied by profiling the stages in the acclimatization process between the CFW and MCS and investigating the feasibility of biogas production using different TS content of CFW. The profiles of anaerobic digestion were shown in this study; however, it is suggested to prolong the fermentation time for a better profiling stage. While biogas production showed an increasing trend with increasing TS content. This proved that the biogas production is highly dependent on the TS content of CFW undergoing the process of AD.

ACKNOWLEDGEMENT

The authors thanked the research grant FRGS/1/2021/TK0//UIAM/02/19 and the Ministry of Higher Education Malaysia for supporting this work.

REFERENCES

[1] Current world population. Worldometer. https://www.worldometers.info/world-population/

[2] Dhir, R. (2023, June 2). Nonrenewable resource: Definition, features, and examples. Investopedia. https://www.investopedia.com/terms/n/nonrenewableresource.asp

[3] Perea-Moreno, M. A., Samerón-Manzano, E., & Perea-Moreno, A. J. (2019). Biomass as Renewable Energy: Worldwide Research Trends. Sustainability 2019, Vol. 11, Page 863, 11(3), 863. https://doi.org/10.3390/SU11030863

[4] Noor, Z. Z., Yusuf, R. O., Abba, A. H., Abu Hassan, M. A., & Mohd Din, M. F. (2013). An overview for energy recovery from municipal solid wastes (MSW) in Malaysia scenario. Renewable and Sustainable Energy Reviews, 20, 378–384. https://doi.org/10.1016/J.RSER.2012.11.050

https://doi.org/10.31436/iiumecp.v1i1.3007

[5] Chen, H. L., Nath, T. K., Chong, S., Foo, V., Gibbins, C., & Lechner, A. M. (2021, March 8). The Plastic Waste Problem in Malaysia: Management, recycling and disposal of local and global plastic waste - SN Applied Sciences. SpringerLink. https://link.springer.com/article/10.1007/s42452-021-04234-y

[6] Bhatia, S. C. (n.d.). *Advanced Renewable Energy Systems*. ScienceDirect. https://www.sciencedirect.com/book/9781782422693/advanced-renewable-energy-systems

[7] Adekunle, K. F., & Okolie, J. A. (2015). A Review of Biochemical Process of Anaerobic Digestion. Advances in Bioscience and Biotechnology, 06(03), 205–212. https://doi.org/10.4236/ABB.2015.63020 S. A. Muyibi and L. M. Evison. "Coagulation of Turbid Water and Softening of Hard Water with Moringa oleifera Seeds," Intern Journ. Environmental Studies, 1996, Vol. 49, pp 247-259, 1996.

[8] Duan N, Dong B, Wu B, Dai X (2012) High-solid anaerobic digestion of sewage sludge under mesophilic conditions: feasibility study. *Bioresour Technol* 104: 150–156.

[9] Brack, P., Dann, S., Wijayantha, K. G. U., Adcock, P., & Foster, S. (2016, August 17). *A simple, low-cost, and robust system to measure the volume of hydrogen evolved by chemical reactions with aqueous solutions*. Journal of visualized experiments : JoVE. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5091921/

[10] Yi, J., Dong, B., Jin, J., & Dai, X. (n.d.). Effect of increasing total solids contents on anaerobic digestion of food waste under mesophilic conditions: Performance and Microbial Characteristics Analysis. PLOS ONE. https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0102548

[11] Pearse, L. F., Hettiaratchi, J. P., and Kumar, S. (2018). Towards developing a representative biochemical methane potential (BMP) assay for landfilled municipal solid waste – a review. Bioresour. Technol. 254, 312–324. doi: 10.1016/j.biortech.2018.01.069

[12] Al-Wahaibi, A., Osman, A. I., Al-Muhtaseb, A. H., Alqaisi, O., Baawain, M., Fawzy, S., & Rooney, D. W. (2020, September 24). Techno-economic evaluation of biogas production from food waste via anaerobic digestion. Scientific reports. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7515879/

[13] Silva, I. M. O., & Dionisi, D. (2020, June 8). Effect of the operating conditions on the anaerobic digestion of wheatgrass for chemicals and energy production - biomass conversion and Biorefinery. SpringerLink. https://link.springer.com/article/10.1007/s13399-020-00735-9