Startup of a semi-continuous anaerobic reactor operated at variable temperature

Emiliano Gutiérrez-Domínguez, Simón González-Martínez

Institute of Engineering, National University of Mexico (Universidad Nacional Autónoma de México), 04510 Mexico City, Mexico

Keywords: anaerobic digestion, municipal solid waste, methane production, temperature variation

Presenting author email: emilianogtz369@comunidad.unam.mx

Introduction

The startup of an anaerobic reactor presents significant challenges due to the need to stabilize microbial populations and control multiple critical parameters. During this initial phase, factors such as the type and adaptation of the inoculum, solids content, organic loading rate, and feeding strategy must be carefully managed to avoid the accumulation of volatile fatty acids and other inhibitory intermediates. Synchronizing the acidogenesis and methanogenesis processes is essential to ensure operational stability and maximize biogas production, highlighting the complexity and time required to achieve a functional system balance (Biswabandhu and Debabrata, 2016). In emerging countries, such as Mexico and other Latin American nations, anaerobic digestion is primarily implemented in small-scale reactors, commonly called domestic or rural biodigesters. These reactors generally lack heating systems and operate at ambient temperatures, which vary significantly throughout the year. These conditions can affect process efficiency due to the microorganisms' sensitivity to thermal fluctuations, posing a challenge to maintaining stability and productivity in these facilities (Anaya-Reza et al., 2024). Reactors operating at lower temperatures experienced stability issues due to the accumulation of volatile fatty acids, which resulted from a reduced metabolic rate of methanogenic bacteria. Therefore, it is recommended not to exceed an organic loading rate of 2 $g_{VS}/L \cdot d$ under mesophilic conditions (Ossa-Arias and González-Martínez, 2021).

This research focuses on the startup of a semi-continuous wet anaerobic reactor and its subsequent operation under variable temperatures, using the organic fraction of municipal solid waste (OFMSW) as substrate.

Materials and methods

The methodology is divided into two stages: 1) the startup of the reactor at a constant temperature of 32°C after inoculating with granular sludge from a large brewery and 2) after reaching stability, operation with decreasing temperature from 32°C to 21°C at a rate of 1°C per week. OFMSW was obtained from the Coyoacán transfer station in Mexico City and processed using an extruder and a plate mill to achieve a homogeneous particle size of approximately 1 mm. The inoculum consisted of anaerobic sludge from a brewery wastewater treatment. The experiment was conducted in a jacketed glass reactor with a total capacity of 5 L, and an effective volume of 4 L. Measuring biogas production was made with an AMPTS II (Bioprocess Control, Sweden) biogas meter, while methane content in the biogas was determined via gas chromatography. Additionally, the pH and alkalinity in the reactor were analyzed using a pH meter, and volatile fatty acids (VFA) concentration was periodically monitored by chromatography. Substrate feeding was made by adjusting the organic loading rate (OLR) to 1 $g_{VS}/L \cdot d$, solids retention time (SRT) of 30 days, feeding every seven days, and continuous mixing.

Results and discussion

Stage 1. After initiating reactor feeding, on day 18, a peak in volatile fatty acid (VFA) concentration was observed, reaching approximately 390 mg/L, followed by a decrease in pH, low biogas production, and a reduction in methane concentration (Figure 1a). These factors indicate decreased activity of methanogenic archaea. To reduce VFA concentration in the reactor and promote methane biogas production, on day 32, 0.336 kg of fresh sludge (washed and centrifuged three times) was added, with a volatile solids concentration of 99 g_{VS}/kg of sludge, equivalent to a total of 33.3 g of volatile solids incorporated into the reactor. Figure 1b shows a significant decrease in VFA concentration and an increase in pH, along with the resumption of biogas production and an increase in methane concentration, reaching approximately 50%.

By day 48, pH, which had risen after adding fresh sludge, dropped again, while VFA concentration began to increase. Additionally, biogas production exhibited an irregular pattern, characterized by high biogas production two to three days after feeding the reactor, followed by a decline in production and an increase in methane concentration as the week progressed. To stabilize conditions, feeding changed weekly to daily, aligning substrate availability with bacterial kinetics and limiting excessive VFA production (Jojoa-Unigarro and González-Martínez, 2023). The reactor operated under these conditions until day 59 when continuous agitation was suspended to prevent further acidification. Although VFA concentration remained stable, pH decreased due to low partial alkalinity. On day 69, the particle size of the organic fraction of municipal solid waste (OFMSW) was increased to avoid overstimulation of hydrolysis and acidogenesis, which could lead to VFA accumulation, pH drop, and process failure (Kouichi, et al., 2010). By day 75, pH reached a minimum value of 6, along with a decrease in partial alkalinity. Simultaneously, biogas production ceased, and methane concentration in biogas dropped to a minimum of 25%, while VFA concentration remained stable (Norio, et al., 2012). To stabilize the reactor, calcium bicarbonate was added to the reactor to increase partial alkalinity and, consequently, stabilize pH.

The organic loading rate was reduced from 1 to 0.5 g_{VS}/L·d. As expected, following these interventions, an increase in partial alkalinity was observed, followed by the reactivation of biogas production, which began to stabilize while methane concentration in biogas increased. From then on, pH remained stable within a range of 7 to 7.5.

Stage 2. The reactor continued operating under these conditions from days 75-108. VFA began to increase from day 89, reaching a maximum of 600 mg/L on day 108; biogas production remained constant, and methane concentration in biogas continued to increase. Figure 1 shows that during this stabilization period, pH remained stable, likely due to the addition of calcium carbonate on day 75, which provided sufficient alkalinity to buffer the acidity generated by the increase in VFA concentration.

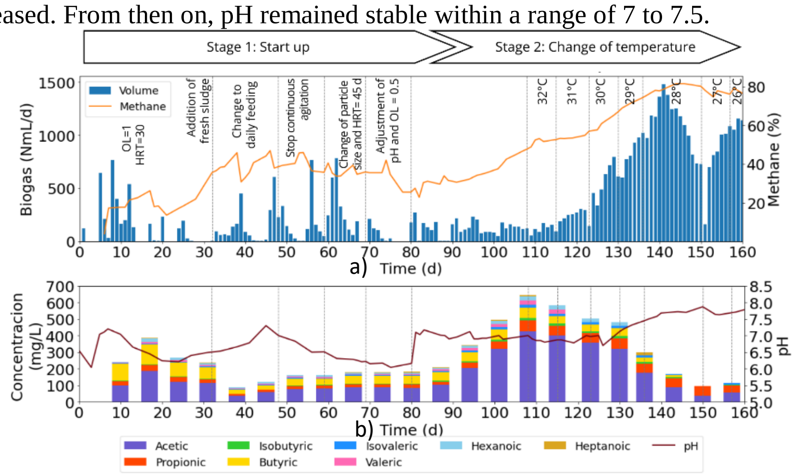

Figure 1. a) Biogas production and methane concentration. b) VFA concentration and pH

On day 115, the second experimental stage was initiated, reducing reactor temperature by 1°C, as biogas production and pH had remained stable, while methane content in biogas exceeded 55%. Figure 1 shows that on day 115, the daily biogas production volume began to increase 45 days after modifying the hydraulic retention time and particle size (45 days and 8 mm, respectively). On day 126, with a temperature of 30°C, methane content in biogas reached 60%. This increase occurred 46 days after reducing the organic load, coinciding with the solids retention time. On day 141, at a temperature of 28°C, the highest biogas production was recorded, reaching a total volume of 1,482 mL/d with a methane concentration of 79%.

It is important to note that the second experimental phase is ongoing, and upon its completion, further analysis will be conducted to assess the long-term effects of temperature reduction and other operational changes. Full results and a detailed analysis will be available by the time of the congress presentation.

Conclusions

During the initial operation weeks, biogas production was highly unstable, and methane concentration in the gas remained low. The operational adjustments led to reactor stabilization, which became evident when biogas production increased along with methane concentration. After reaching stability, the temperature reduction did not disrupt the process performance. Stability was detected when methane concentration in the biogas improved, and biogas production increased, suggesting microbial adaptation to temperatures. Anaerobic digestion of municipal solid waste under lower mesophilic and psychrophilic temperatures is possible under lower temperatures.

Acknowledgment. Financing was provided by the General Directorate for Academic Affairs at the National University of Mexico, PAPIIT IT100523. Thanks to SECIHTI (former CONAHCYT) for the MSc scholarship. The authors acknowledge Dr. Francisco Rojo-Calleja for the analytical support at the Chemistry School at UNAM.

References

Alavi-Borazjani, S.A., Capela, I., Tarelho, L.A.C.: Over-acidification control strategies for enhanced biogas production from anaerobic digestion: A review. *Biomass and Bioenergy*, 143, 105833 (2020). https://doi.org/10.1016/j.biombioe.2020.105833

Anaya-Reza, O., Altamirano-Corona, M., Basurto-García, G., Patricio-Fabián, H., García-González , S., Martinez-Hernandez, E., Durán-Moreno, A.: Wet anaerobic digestion of organic fraction of municipal solid waste: experience with long-term pilot plant operation and industrial scale-up. *Bioprocess Biosyst Eng*. 47, 235–247 (2024). https//doi:10.1007/s00449-023-02958-2

Biswabandhu, C., Debabrata, M.: Anaerobic digestion for the stabilization of the organic fraction of municipal solid waste: A review. *Environmental Reviews*, 24(4), 426-459 (2015). https://doi.org/10.1139/er-2015-0077

Jojoa-Unigarro, G., González-Martínez, S.: OFMSW Fermentation with Different Inocula and Its Effects on Methane Production. *Waste Biomass Valor*, 14, 1461-1476 (2023). https://doi.org/10.1007/s12649-022-01968-7

Kouichi, I., Yu-ki, O., Norio, N., Chiaki, N., Shuichi, Y., & Tatsuki, T. Effects of particle size on anaerobic digestion of food waste. *International Biodeterioration & Biodegradation*, 64, 601-608 (2010). https://doi.org/10.1016/j.ibiod.2010.06.013

Norio, N., Nobuyuki, T., Minako, K., Chiaki, N., Norio, K., Tatsushi, M., Fatimah, Md. Y., Tatsuki, T. Maximum organic loading rate for the single-stage wet anaerobic digestion of food waste. *Biores Technol*, 118, 210-218 (2012). https://doi.org/10.1016/j.biortech.2012.05.045

Ossa-Arias, M.D.M., González-Martínez, S.: Methane production from the organic fraction of municipal solid waste under psychrophilic, mesophilic, and thermophilic temperatures at different organic loading rates. *Waste and Biomass Valor*, *12*, 4859-4871 (2021). https://doi.org/10.1007/s12649-021-01354-9