Designing and building a lab-scale solid state anaerobic digester coupled with a bioelectrochemical treatment to process food waste: A Reflection

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Introduction

In order to advance food and animal waste management, scientists have attempted to find ways to use waste materials to produce energy or other more profitable substances [1, 2]. Anaerobic digestion (AD) is one such technique, employing microorganisms to break down organic matter in an oxygen-free tank called an anaerobic digester. Anaerobic digesters are continuously fed organic feedstock such as food waste or manure. Depending on the solid content of the feedstock going into the digester, AD is classified as either solid state (total solids over 15%) or liquid state (total solids below 15%) [2, 3]. The system outputs biogas (collected in bags) and liquid, nutrient-rich digestate (collected in the lower reactor compartment). This blend is usually kept warm (~ 100°F) and mixed inside the airtight container to ensure the organic substrates and microorganisms can go through multiple stages of action. First is hydrolysis, where bacteria takes apart the large complex molecules inside the food, such as proteins, fats, and carbohydrates. Next, sugars, amino acids, and long-chain fatty acids are converted into short-chain volatile fatty acid (VFAs) in a process called acidogenesis. These acids are valuable hydrocarbon chains that can form methane through methanogenesis. These microbial processes produce biogas made up of methane, carbon dioxide, water vapor, and other trace compounds. Biogas is a renewable energy: methane can be converted into electricity or used as another energy source to heat buildings. The remaining digester residue, digestate, is made up of tiny solid fibers and liquids that can be pasteurized to produce a biofertilizer [1, 2].

AD not only keeps organic scrap materials out of landfills, but also returns valuable energy resources [1]. Solid state AD is becoming more commercially widespread because industries don't have to add water to the mixture, using less equipment and energy [3,4]. Because solid state AD is a promising technology for treating food waste with high solid contents, research is currently being done to develop new digesters to increase process stability and biogas production efficiency. One such suggested solution is adding a bioelectrochemical (BEC) treatment to the solid state AD system.

Project Overview

From late January to late April 2019, I aided Dr. Bo Hu, Associate Professor, and Dr. Lingkan Ding in their bioprocessing lab. Their lab patented a BEC system that we applied in addition to solid state AD of food waste. The BEC raised the pH of the system, thus increasing the stability of the AD process and biogas production. My project focused on using the system that attempted to combine these two technologies. In order to maximize system stability and biogas production, a two-stage process was created which separated solid-state hydrolysis from liquid leachate AD.

The lab-scale solid-state AD consisted of a chamber separated into two compartments. The upper compartment held the mixture of food waste and inoculum (solid digestate from an industrial dry digester), while the liquid leachate was filtered into the lower compartment. It was this lower compartment leachate which could be refined bioelectrochemically. This next BEC-assisted step of liquid AD was intended to increase system stability and produce higher levels of biogas.

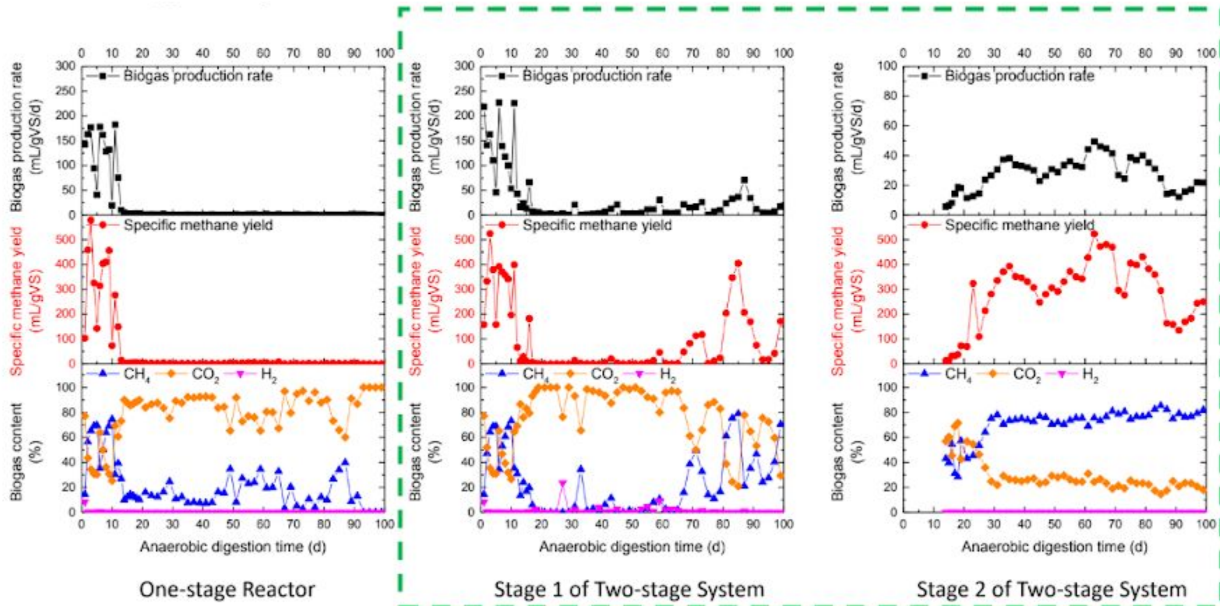
Project Summary

For the two-stage system tests, three separate reactors were built: G1, G2, and N1. G1 was a on-stage control group. The experimental groups were broken into two stages in the G2 and N1 reactors. Food waste was hydrolyzed and acidified into VFAs in the G2 reactor, which was a 4-L container with a 2-L working volume. The VFAs-enriched liquid leachate was then transferred into N1, a 2-L liquid digester with a 1.4-L working volume. This is where the second stage (methanogenesis) occurred. In order to measure biogas production before recirculating the leachate, the BEC system was not initially attached to the digester. The digesters were then kept at 37 °C for 99 days while biogas, leachate, and digestate samples were collected. Samples were tested on traits such as their composition, pH, and VFA profiles. Other tests such as total ammonia content, chemical oxygen demand, and total alkalinity were indicators of how well the microbes could function in the given environment. Once enough data was collected through the previous two experiments, the lower cavity of the digester was paired with a BEC system: two low carbon steel electrodes charged at 0.7 volts. For these BEC-assisted AD tests, four groups were established using 500-mL reactors with a working volume of 400 mL. Different conditions including addition of BEC, addition of biochar, combination of BEC and biochar were compared on the basis of their effects on biogas production. The same procedure as the previous experiments was applied to the system coupled with the BEC. The differences between the two systems' percentage of solids, biogas production, and percentage of methane, carbon dioxide, hydrogen, and hydrogen sulfide were noted. The reactor system was then optimized by varying BEC voltage, recirculation rate of leachate, and feedstock concentration.

I devoted about 10 hours a week on this project for 12 weeks. During that time, I helped prepare the feedstock, build and fix the digesters, take samples, test samples, and properly dispose of the used chemicals. I practiced techniques such as dilution, flushing, micropipetting, and proper scaling. I used technology such as a gas chromatographer to measure gas content, a multimeter to measure voltages, a conductivity meter to measure conductivity, and a centrifuge to separate samples.

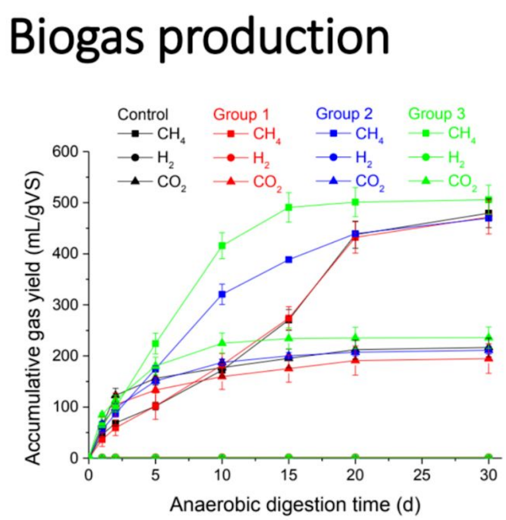
Results

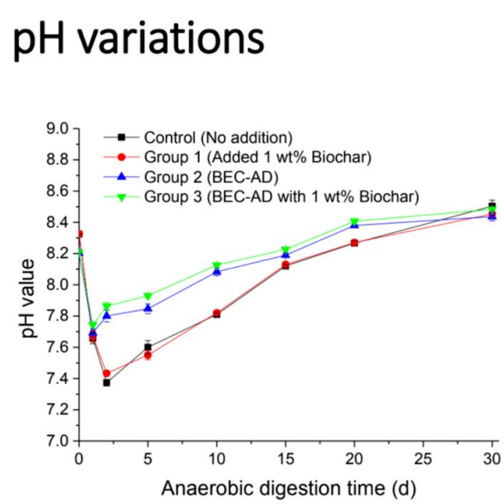
The project had some drawbacks: exploding digesters, leaking test tubes in the centrifuge, and an overall learning curve of correct practices and procedures. However, initial hypotheses were supported: a two-stage solid-state AD was more stable than a simple one-stage reactor, and the BEC-assisted AD system performed biogas production rates and better buffering capacity. Preliminary tests without the BEC displayed that while a one-stage reactor became unstable when food waste input increased, a two-stage process managed to increase food waste degradation in Stage 1 and maintain higher levels of biogas production in Stage 2.



Graph 1: Comparisons of biogas production rate, methane yield in biogas, and biogas total content between one and two-stage reactors.

This means that a two-stage system can take a higher input of food waste while alleviating some of the concerns associated with solid-state AD. As noted in the graphs, the highest levels of biogas production were observed after two weeks at the food waste loading of 400g. Filling up the digester with too much initial food waste resulted in system failure, regardless of being a one or two-step system, because without further leachate dilution, total ammonia built up and inhibited microbial activity, thus messing up the system.





Graphs 2 and 3: Anaerobic digestion paired with BEC treatment resulted in a higher biogas production rate and increased the buffering capacity (pH) of the system in the starting stages.

As shown in Graphs 2 and 3, adding the BEC increased buffering capacity and enhanced the biogas production rate in the first stages of the AD process, The next steps of this experiment would be to analyze current density and coulomb efficiency in the BEC, and to add BEC to a typical solid-state anaerobic digester in order to compare process efficiency and biogas production. This work is an important step in enabling businesses to utilize solid state AD in an urban setting, fixing both economically wasteful practices and environmental concerns.

Reflection

This Undergraduate Research Opportunity enabled me to strengthen not only my lab skills, but also my confidence in my general scientific ability. Working on a scientific project that spanned over two weeks was more than I had ever encountered before, not to mention a few months. This extended time period meant that I could get over the nerves and mistakes in a learning curve, and become comfortable in a lab and my duties within it. By the end of this semester, I was comfortable carrying out most procedures related to the anaerobic digester unaided, while I had just learned what an AD was when I started. Working in a lab meant I could see a professional lab setting and understand the workplace dynamic. I could also see how long-term projects are usually designed, maintained, and lobbied for. All of these experiences mean that I can pick up lab procedures, data analysis, and workplace communication in a new scenario much faster than I could before. I know these experiences make me a more competitive student job applicant, so I will be sure to capitalize on these new skills for the next three years of my college career.

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