An Evaluation of Mainstream Anaerobic Fluidized Bed Reactors (AFBR) to Treat Domestic Wastewater

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Introduction

Aerobic secondary treatment systems for domestic wastewater are energy intensive and expensive. In the United States, 3% of all electric energy usage is used to treat wastewater (EPA Office of Water, 2006). Due to concerns about sustainable resource usage, researchers are now reframing domestic wastewater as a resource rather than as a waste product that needs to be remediated and eliminated. Anaerobic treatment of domestic wastewater is a viable alternative to traditional aerobic treatment due to its resource efficiency.

One promising anaerobic secondary treatment system is the Staged Anaerobic Fluidized-Membrane Bioreactor (SAF-MBR) (Shin, McCarty, Kim, & Bae, 2014). The SAF-MBR consists of two reactors, an anaerobic fluidized bed reactor (AFBR) and an anaerobic membrane bioreactor (AnMBR). Although this system produces high quality effluent and promises energy production with further development, it relies on costly membrane filtration within the AnMBR. Submerged membranes are currently needed within the system to increase solids retention time (SRT) of particulate substrate to avoid limitations in hydrolysis. These membranes are problematic not only because they require a high initial investment cost, but also because they require continuous maintenance due to membrane fouling. The removal of incoming particulates, measured in the form of particulate chemical oxygen demand (PCOD), is necessary to remove the need for membranes and to encourage more methane production. Alternatives to membrane-focused anaerobic treatment technology are needed to optimize resource recovery efforts. The objective of my project is to explore methods to eliminate the need for membranes by removing PCOD within primary treatment while encouraging methane production in the AFBR system.

Our evaluation focuses on bench-scale experiments that investigate the effect of chemically enhanced primary treatment (CEPT) on the removal of PCOD and the production of methane. If PCOD can be removed within primary treatment, membranes may no longer be needed. Within a larger system, the proposed CEPT would function as a coagulation system after grit removal. CEPT supernatant would be fed into an AFBR and the settled material would be transferred to an anaerobic digestor.

Methods

Pilot Scale SAF-MBR

Biofilmed granular activated carbon (GAC) was harvested from the AFBR at the Codiga Resource Recovery Center (CR2C), a pilot scale SAF-MBR system that operates on the Stanford campus. Effluent from the grit tank and bulk liquid from the AFBR were also collected.

Jar Test and COD Analysis

To determine the optimum dosage of coagulant for CR2C wastewater, a jar test was conducted. The coagulant utilized was ferric chloride, a compound that was determined in previous tests to be the most effective coagulant for the CR2C waste stream. Several beakers were filled with 1000 mL grit tank effluent and given varying dosages of the coagulant (0, 10, 30, 50, 70, 90 ppm Fe^{3+}). Equivalent doses of sodium bicarbonate were also added to avoid pH change. The samples were subjected to 1 minute rapid mix (150 rpm), 20 minutes slow mix (50 rpm), and 15 minutes settling using a standard jar test apparatus. This sequence mirrors the traditional water treatment set-up of chemical dosing, flocculation, and sedimentation. The supernatant for each dosage amount was tested for total and soluble COD to determine PCOD. Optimum dosage was determined at the lowest dose at which PCOD reached a favorable level.

Biochemical Methane Potential Assay

Biochemical Methane Potential (BMP) assays determine the amount and rate at which a substrate can be anaerobically converted to methane. BMP assays were used to determine how the GAC within the AFBR would process CEPT supernatant in comparison to grit tank effluent. Bulk liquid from the AFBR was added as well to ensure proper transfer of important hydrolysis enzymes. Samples were kept in sealed serum bottles with 100 mL liquid solution, 15

mL GAC, 0.3 mL bulk AFBR bulk liquid, and 45 mL gas headspace. To ensure an anaerobic environment, headspace and control solutions were purged with N_2 gas. Test solutions were not purged because they were anaerobic. The assay includes a negative control that provides a baseline (GAC+ DI water) and a positive control that models a known response (GAC+ acetate). The two experimental parameters were the CEPT supernatant and the grit tank effluent, each also bottled with GAC and bulk liquid. All were diluted to maintain a constant COD typical of the CEPT supernatant. Each sample was tested in duplicate. Samples were kept on a shaker table at 37 ºC. Gas volume production measurements were taken at 37 ºC and a gas chromatograph was utilized to monitor gas species concentrations in the headspace.

Rate Kinetics: Determining Rate Constants

Data were modeled using consecutive reaction first order kinetics. The positive control data were used to determine the first kinetic constant, k_a, which represents the conversion of acetate into methane. The CEPT and without CEPT data were used to determine two separate hydrolysis rate constants, k_h. All data processing was conducted using Excel. These rate constants were used to determine the hydrolysis efficiency of the two primary treatment methods in a plug flow reactor (PFR) and a continuously stirred tank reactor (CSTR) over time.

Results and Discussion

Jar Test and COD Analysis

A ferric chloride dose of 50 ppm Fe^{3+} was determined to be the optimal concentration for PCOD reduction. This dosage had 12 ppm PCOD. Higher dosages did not demonstrate significantly lower levels of PCOD. Figure 1 shows COD levels at different coagulant doses.

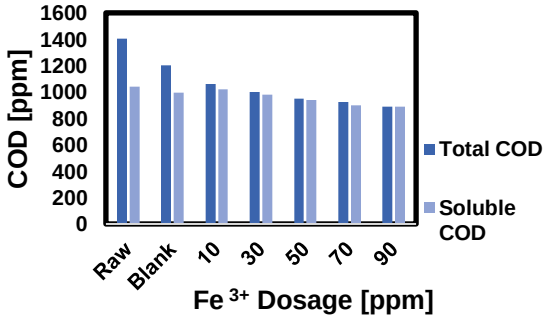

Figure 1. COD variance with coagulant dosage.

BMP Assay

Substrate consumption was monitored through methane production over time. These data are shown in Figure 2 below. Deviation between duplicates was negligible.

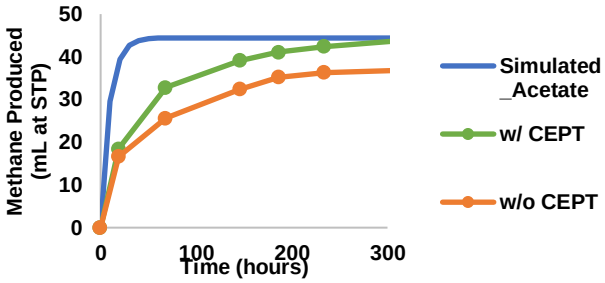

Figure 2. Methane production over time for BMP test.

Rate Kinetics

Modeling the data shown above resulted in a k_a of 0.11 $hour^{-1}$ and k_h values with CEPT of 0.024 $hour^{-1}$ and without CEPT of 0.020 $hour^{-1}$. These rate constants were used to calculate the hydrolysis efficiency of the GAC with the given substrate. Table 1 shows the hydraulic retention times (HRT) necessary to achieve an accepted hydrolysis efficiency. The values for the CSTR are of the most interest, as an AFBR is most similar to a CSTR.

Table 1. HRT in hours required to achieve 90% hydrolysis efficiency for the respective reactor types and substrate.

	PFR	CSTR
w CEPT	95	360
w/o CEPT	115	430

Conclusion

Although CEPT enhances hydrolysis rate, the corresponding hydrolysis efficiency levels are not promising. The lengthy HRT required for necessary hydrolysis efficiency, as shown in Table 1, demonstrates that CEPT in tandem with an AFBR is not a viable alternative to membrane-focused anaerobic secondary treatment. The typical HRT within a SAF-MBR system is 4 hours, whereas the HRT within this proposed system would be 360 hours. The membranes ensure that the solids retention time is much longer (> 480 hours) to create an adequate time for hydrolysis and PCOD breakdown, while keeping the HRT low. At this point, membranes are necessary to efficiently achieve a sufficient level of COD removal.

Sources

EPA Office of Water. Wastewater Management Fact Sheet, Energy Conservation, EPA 832-F-06-024; U.S. Environmental Protection Agency: Washington DC, 2006; p 7.

Shin, C., Mccarty, P. L., Kim, J., & Bae, J. (2014). Bioresource Technology Pilot-scale temperate-climate treatment of domestic wastewater with a staged anaerobic fluidized membrane bioreactor (SAF-MBR). *Bioresource Technology*, *159*, 95–103. https://doi.org/10.1016/j.biortech.2014.02.060