THE ROLE OF VISCOSITY IN MESOPHILIC ANAEROBIC DIGESTION

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Background

Anaerobic digestion is the biological process in which organic matter is converted into biogas. Anaerobic digestion is conducted by several classes of microorganisms, each of which use the product of the previous microorganism reaction as its substrate.

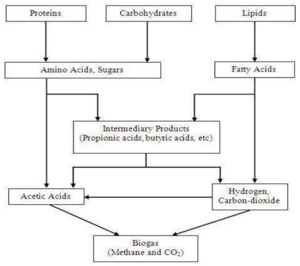

Figure 1. Steps in the anaerobic digestion process
Source: https://www.researchgate.net/publication/262033577_Biogas_Generation_through_Anaerobic_Digetsion_Process_-_An_Overview

- The first step in the anaerobic digestion process, when the proteins, carbohydrates, and lipids are converted into amino acids, sugars, and fatty acids is the hydrolysis phase. Physically, during the hydrolysis phase, hydrolytic enzymes are breaking down and solubilizing particulate substrate.
- The hydrolysis step is considered to be the rate-limiting step in the anaerobic digestion process.

Introduction

- Literature suggests that the kinetics within activated sludge are diffusion-limited
- Diffusion limitations within mesophilic anaerobic digestion (MAD) are largely unknown.
- Diffusion can be described by Fick's First Law (Equation 1). De is the effective diffusivity of the activated sludge. There are two main contributions to the effective diffusivity: the boundary layer and the biofilm. Figure 2 shows a visual representation of what these layers look like in an activated sludge floc.
- The diffusivity is affected by many parameters including viscosity. The bulk viscosity affects the diffusivity of the boundary layer.

$$r_d = -D_e \frac{\partial S}{\partial x} * A$$

- **r_d:** Rate of diffusion [g/day]
- **D_e:** Effective diffusivity
- **dS/dx:** Gradient layer thickness [g/m]
- **A:** Particle size [m^2]

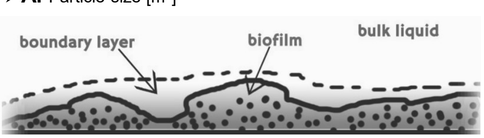

Figure 2. Biofilm and boundary layer graphic
Source: http://2011.igem.org/Team:ZJU-China/bio-modeling.html

Objective

- Explore the role of the bulk viscosity in determining the performance of activated sludge within MAD.

Methodology

- Batch tests were performed to analyze the effect of viscosity on the hydrolysis rates. 250 mL bottles were used and each condition was tested in triplicate. The batch bottles were connected to Respirometers and the biogas production was monitored over the course of a 24-hour time period.

Figure 3. Respirometers attached to batch test set-up

- The biogas production rate curves were produced from the Respirometer data for each batch test and were normalized based on the weight of the volatile solids in each batch bottle.
- The hydrolysis rate was the parameter that was used for the sake of comparison to determine the level of the activated sludge's performance on the batch scale. A higher hydrolysis rate is taken to mean a higher level of performance.
- The hydrolysis rate is determined as the average gas production rate displayed on the biogas production rate curve once the curve reaches a steady state. Figure 4 shows a typical biogas production rate curve and the area of the curve that represents the hydrolysis rate.

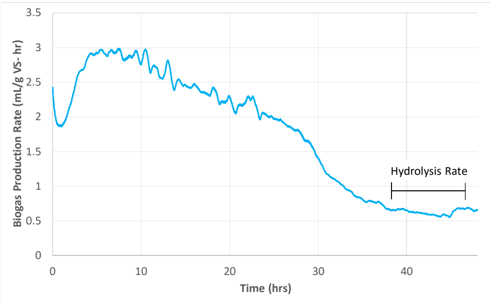

Figure 4. Sample biogas production rate curve with hydrolysis rate noted

Results & Discussion

Test 1:

- Objective: Determine impact of viscosity by varying total solids concentrations, at 300 rpm (73 sec^-1)

Table 1. Batch bottle conditions used for Test 1

Mixing Rate (rpm)	Shear Rate (sec^-1)	%TS	Viscosity (mPa)
300	73	5.17	59.5
300	73	7.11	145.2
300	73	7.31	154.0
300	73	7.63	168.1
300	73	8.58	210.1
300	73	9.56	253.3
300	73	10.32	286.9

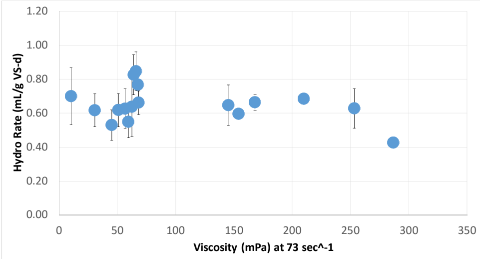

Figure 5. Hydrolysis rate versus viscosity for sludge with varied total solids concentrations

- The normalized hydrolysis rates measured for each condition showed no statistical difference between one another.
- At the high shear rate of 73 sec^-1, the differences in viscosity reflected in each varied %TS condition are smaller than for lower viscosities. This phenomenon is shown in Figure 6.

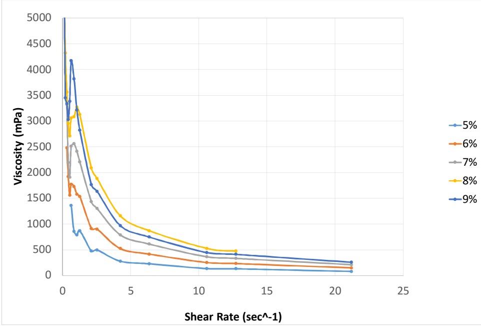

Figure 6. Viscosity versus shear rate curves at varying %TS values

Test 2:

- Objective: Determine impact of viscosity by varying total solids concentrations at various shear rates

Table 2. Batch bottle and shear rate conditions used for Test 2

Mixing Rate (rpm)	%TS	Shear Rate (sec^-1)
0	3%	0
0	5%	0
0	9%	0
100	3%	5.3
100	5%	5.2
100	9%	5.3
300	3%	75
300	5%	73
300	9%	74

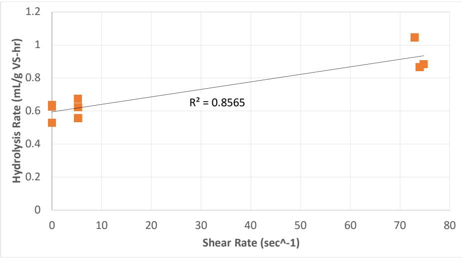

Figure 7. Hydrolysis rate versus shear rate

- There is a strong correlation between increased hydrolysis rates and increased shear rates.
- There was no correlation between increasing %TS and decreasing hydrolysis rates at any of the shear rates evaluated.

Conclusions

- Changing the bulk viscosity of activated sludge affects only the boundary layer of the flocs. Changing the shear rate acting on the activated sludge also affects only the boundary layer of the flocs.
- There were negligible differences in hydrolysis rates for increased bulk viscosities, which indicates that changing the diffusivity of the boundary layer does not have a significant impact on the effective diffusivity of the activated sludge.
- The correlation between hydrolysis rates and shear rates indicates that with higher shear rates, the diffusion resistance due to viscosity is less because at higher shear rates, the viscosities at various %TS concentrations are smaller and thus less limiting.

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