Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY
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Biosystems Design Projects

Process Modeling for a Wastewater Treatment Plant (Under NDA)

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Background

An up-flow anaerobic sludge blanket (UASB) reactor uses microbes to digest and convert organic matter into biogas.

Glanbia's wastewater treatment system implemented a UASB reactor to digest solids in their wastewater. Before the wastewater enters the digester, solids are coagulated with ferric, which introduces iron ions into the system. The coagulated solids and water then enter the digesters and the solids are converted to biogas, which is currently being flared. Any solids not converted in the digester then undergo further removal in the DAF membranes and are recirculated back to the start of the wastewater treatment plant. The two effluents from the system are biogas and clean water.

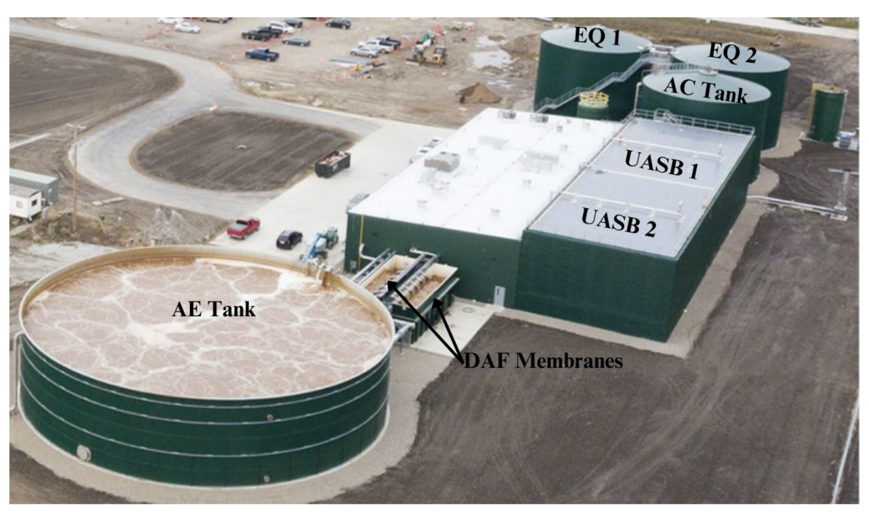

Figure 1. Aerial photograph of the on-site WWTP at Glanbia

Although the system is operating efficiently, there are concerns regarding the accumulation of solids in the reactors, as there is no removal plan for solid accumulation. Solid accumulation can lead to damage to the reactor or system failure.

Problem Statement

Design a mass balance for the system. Create a long-term management plan of solid removal

Objectives

- Create a mass balance for the wastewater process that quantifies carbon, ammonia, metal ions, and sodium in the influent and effluent
- Collect monthly samples at 5 unique points in the system
- Complete total organic carbon, total nitrogen, iron test, total solid, volatile solid, pH test on collected samples to identify any possible accumulation
- Create a trendline of collected data in R
- Recommend removal procedure for excess accumulation of carbon and/or metal ions in the digester

Constraints

- Continue operation at 1.5 M gal of wastewater to be treated every 24 hr
- Keep methane composition in biogas at around 70%
- Keep biogas production above 100,000 ft^3/d
- Maintain the volume of activated granulated sludge in the digester between 10%-30% (Goi et al., 2020)
- Keep ammonia levels below 200 mg/L (Chen et al., 2007)
- Keep pH at 7 (Chen et al., 2007)

Data Collection

- Samples were collected once a month for 5 months starting in October 2023
- Samples are collected at five sampling points indicated in the red circles in Figure 2

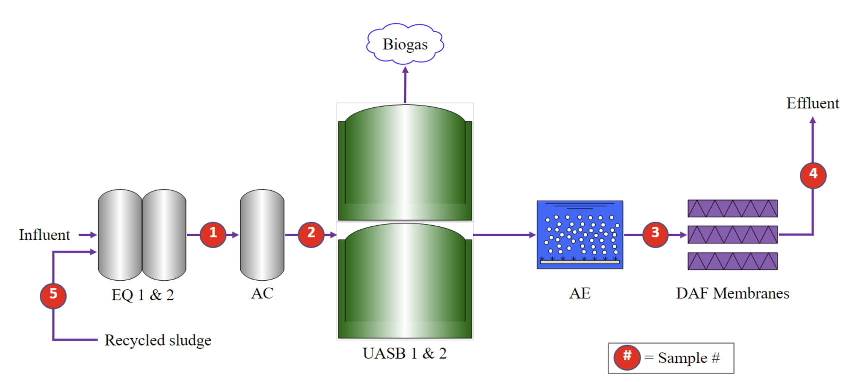

Figure 2. System Flow Diagram with sample collection points

Samples are tested using Hach kits or Shimadzu analyzers at the anaerobic digestion research and education center (ADREC).

Tested for:

- Total carbon
- Total nitrogen
- Total Solids
- Volatile solids
- Metal ions
- pH

Results are presented in concentrations of solids in the water and are sorted by location of sample collection.

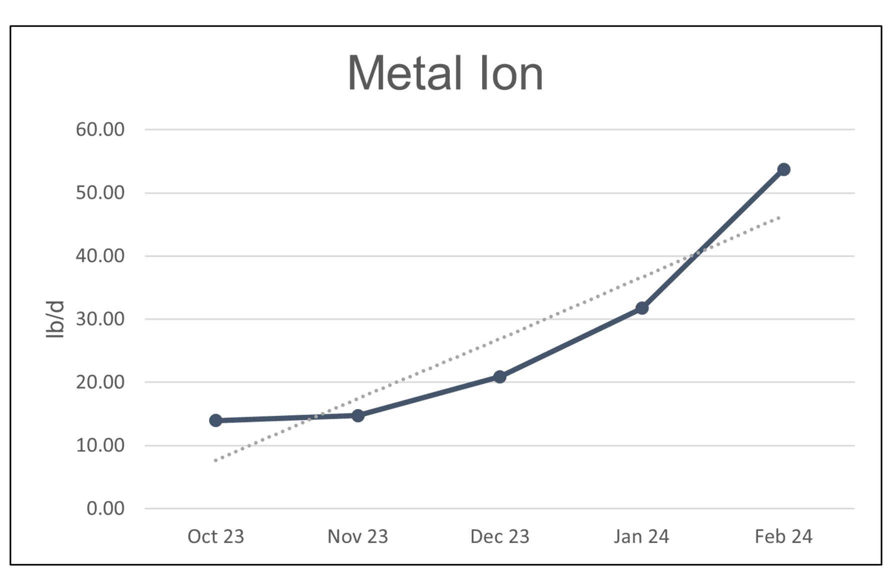

Figure 3. Iron Hatch Kit Results from AC to UASB

- Results showed an increase in the concentrations of carbon and iron
- Results from the tests are analyzed in the mass balance

Metadata

A summary log of Glanbia's critical flow data was sent to the team and refined.

Data is sorted by:

- Influent flow – Process wastewater, Proliant, and Clearwater Flow
- Effluent flow – Clean water being discharged
- Storage of water in the UASB reactor
- Water quality parameters – COD, Phosphorous, and pH
- Biogas data – Temperature of reactors, biogas composition

- Data is monitored by monthly averages
- Critical flow data is statistically analyzed in RStudio

Statistical Analysis

- Used RStudio, an open-source statistical analysis tool to examine flowrates, biogas, and temperature data series
- Shapiro Wilks, One-Way ANOVA, Tukey's honestly significant difference

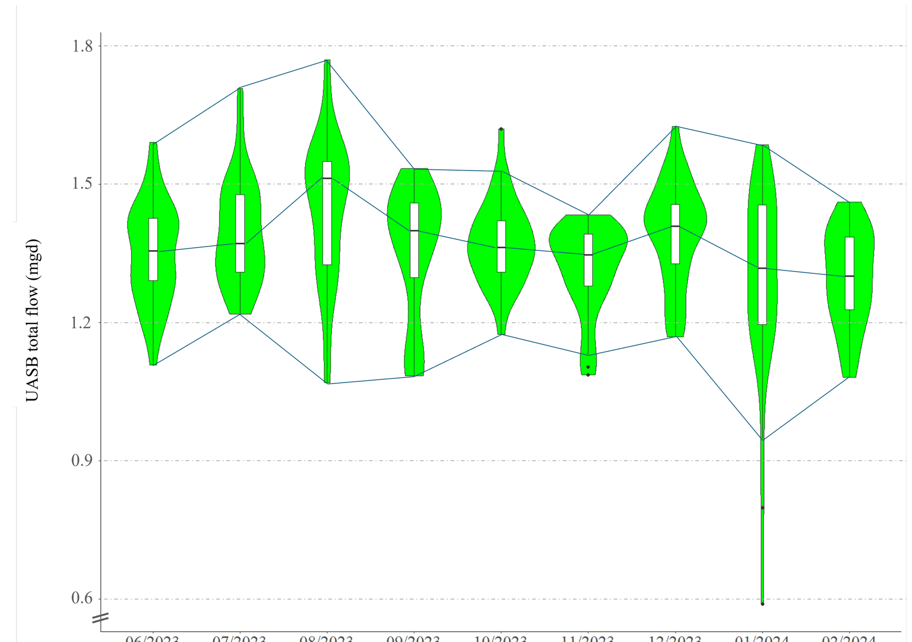

Figure 4. UASB total flow violin plot

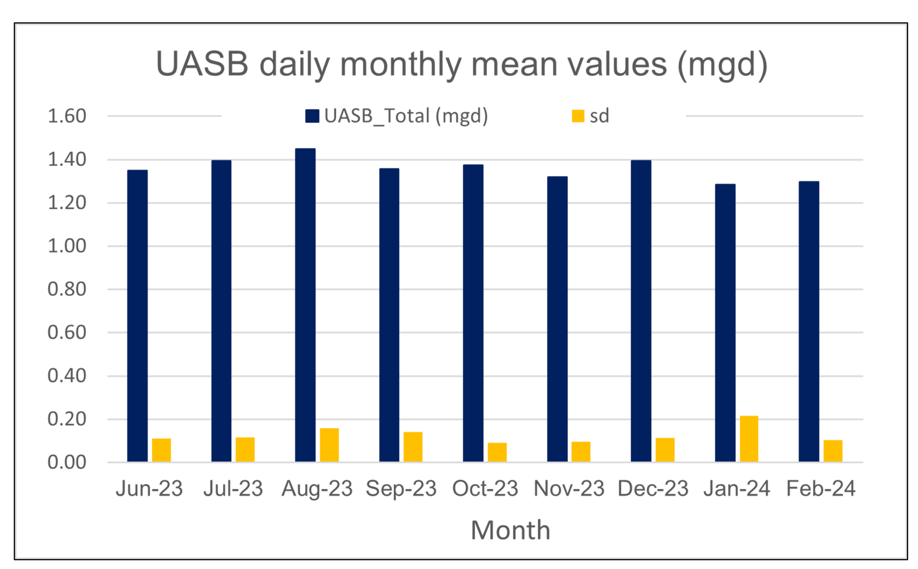

Figure 5. UASB daily monthly mean values

- Violin plots show frequency, distributions, and patterns of data

- Mean flow values will be used to solve the mass balance

Mass Balance

Using the results from the Hach kit testing and daily monthly mean flows from RStudio, the concentration of carbon, nitrogen, and iron were calculated at each sampling location

$$Mass = Daily\ montly\ flow \times Concentration \qquad \text{Eq. 1}$$

- Results for C, N, and Fe were plotted as mass over time
- Between sampling points 3 and 5 from Figure 2 find the accumulation in the digestor
- Points 1-5 are the calculated masses for the first 5 months
- A predictive trendline for the following 7 months was created to predict the accumulation of solids

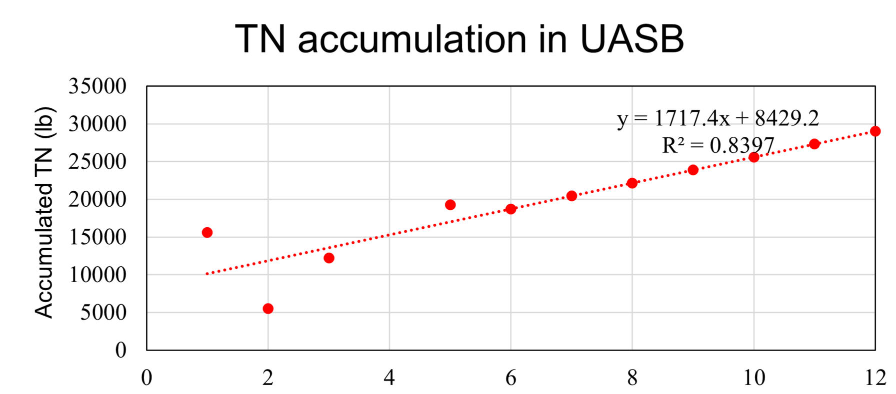

Figure 6. Predictive nitrogen mass accumulation

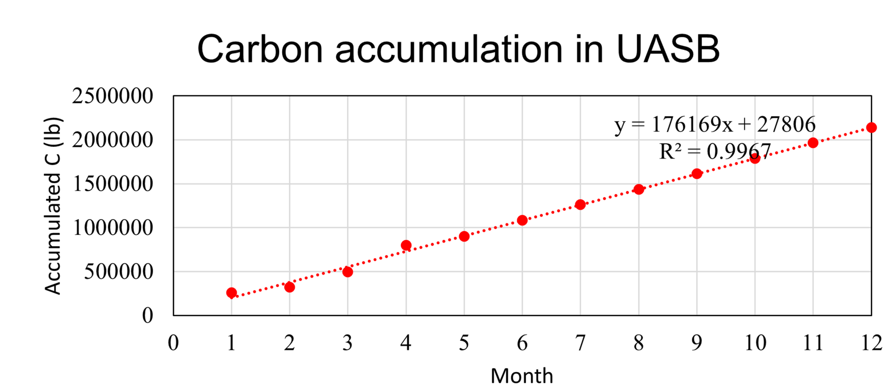

Figure 7. Predictive iron mass accumulation

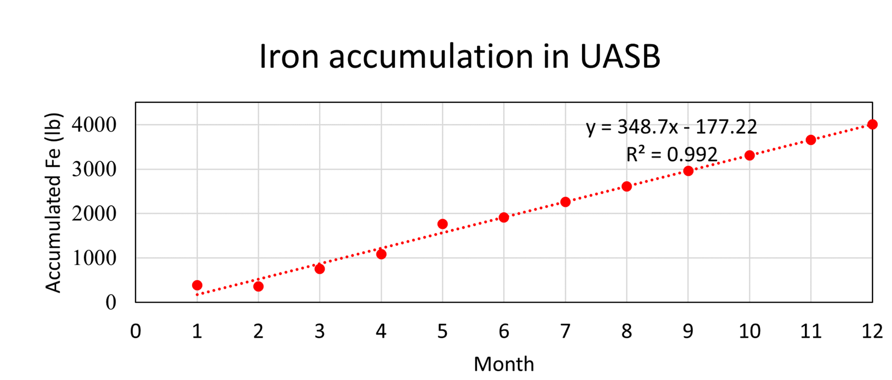

Figure 8. Predictive carbon mass accumulation

- Results of the mass balance show an accumulation of carbon, nitrogen and metal ions in the digestor
- Nitrogen accumulation is minimal and not a threat to the health of the digestor
- Metal ions and carbon are accumulating at a rate that can inhibit the health of the reactor
- Metal ion accumulation poses the greatest threat as a concentration above 5.6 g/L can cause reactor failure

Management Plan

Primary concern of accumulation:

- Metal Ions
- Carbon

A management plan focusing on the removal of iron from the system will also address the accumulation of the C and N as well. The 0-3 ft point in the reactor contains the highest concentrations of metal ions and will be the focus of our management plan.

- A "safe-level" of 4.04 g/L was determined as a target iron concentration
- The difference of predictive iron mass in the reactor was found for each month
- This value was divided by the target concentration of 4.04 g/L to determine the required volume of digestate removal from the reactor

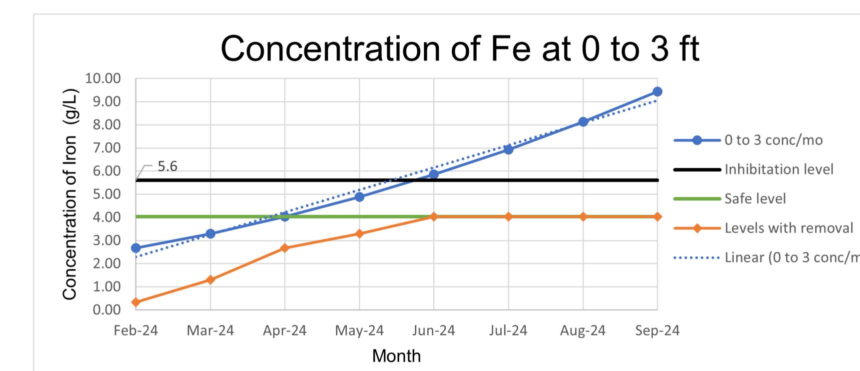

Figure 9. Management Plan Results

- To maintain the target concentration of 4.04 g/L, a discharge is recommended of 32,000 gal/mo
- To ensure iron-concentrated sludge is removed and the microbial community within the reactor is kept healthy, discharge cannot occur all at once
- Discharge is recommended to occur once per week. Exact amounts and frequency are based on the availability of operators and engineers

Select References

Chen Y., Cheng J.J., & Creamer K.S. (2007). Inhibition of anaerobic digestion process: a review, *Bioresource Technology*, *99*(10), 4044-4064. https://doi.org/10.1016/j.biortech.2007.01.057

Goi D., Buttazzoni M., & Mainardis M. (2020). Up-flow anerobic sludge blanket (UASB) technology for energy recovery: A review on state of the art and recent technological advances. *Bioengineering*, *7*(2), 43. https://doi.org/10.3390/bioengineering7020043

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