Using Mathematical Modelling to Identify Causes of Souring During Food Waste Anaerobic Co-Digestion

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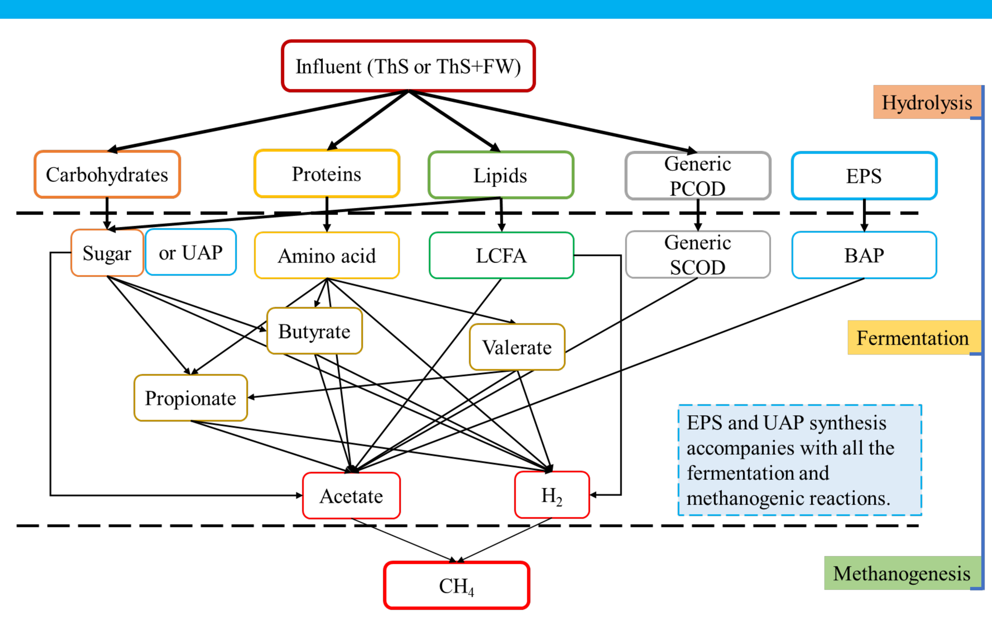
MODELLING FOOD WASTE CO-DIGESTION FOR FAILURE TO IMPROVE OPERATIONAL SUCCESS

We developed a mathematical model to explore the conditions where food waste (FW) anaerobic co-digestion (AcoD) reactors sour based on varying organic loading, hydraulic retention time (HRT), and feeding mode (continuous vs. semi-continuous). The model includes the typical biomass present in AcoD, common FW components (carbohydrates, proteins, lipids) and their hydrolysis products, pH and chemical speciation, alkalinity, and select pH and fatty acid inhibitions. With a long enough HRT and especially with continuous feeding, increasing food waste loading improved pH stability, biogas yield, and methanogen accumulation. AcoD operated with semi-continuous feeding was more sensitive to lower HRT than AcoD with continuous feeding. For example, feeding food waste having 200 g/L TCOD required a minimum HRT of 9 days for continuous feeding, but 19 days for reactors fed every 2 day in semi-continuous mode. The best indicator of the onset of souring was bicarbonate (HCO_3^-) alkalinity. The model and its results will help system designers and operators determine and monitor crucial parameters for municipal and industrial applications of AcoD.

Background

FW accounts for > 12% of municipal solid waste in the US[1] and have high organic carbon content, making them ideal for energy production. Many municipalities are pursuing AcoD of FW and FOG at water resource reclamation facilities, but AcoD operations can be challenging due to rapid fermentation of FW, causing pH to decrease to < 6.0 resulting in souring and methanogenic inhibition. Here, we identify causes and leading indictors of souring under a variety of operating conditions, including organic loading, HRTs, feeding frequency (i.e., semi-continuous vs. continuous feeding).

Mathematical Model Structure



The biochemical structure of the model. **ADM1 was modified to include a variety of components, like extracellular polymeric substances (EPS), utilization associated products (UAP) and biomass associated products (BAP).** LCFA = long-chain fatty acids, ThS = thickened sludge

Model features:

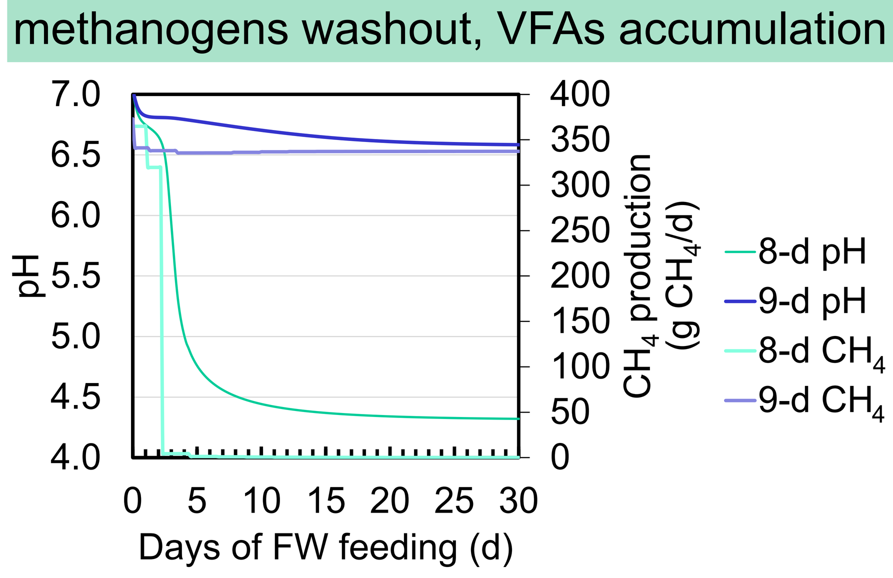
- Executed in MATLAB using ODE15s
- Simulated 200 d of ThS only feeding prior to adding FW to the feed
- Includes biomass typical to anaerobic digestion, including fermenting bacteria, aerobic heterotrophs, and methanogens
- Chemical speciation based on pH
- Gas/liquid phase mass transfer
- **Souring is pH < 6.0**

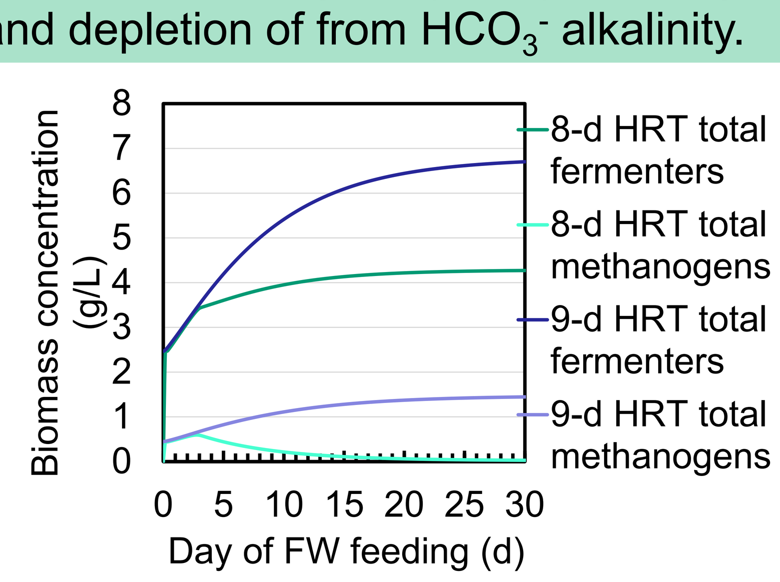
Model inputs

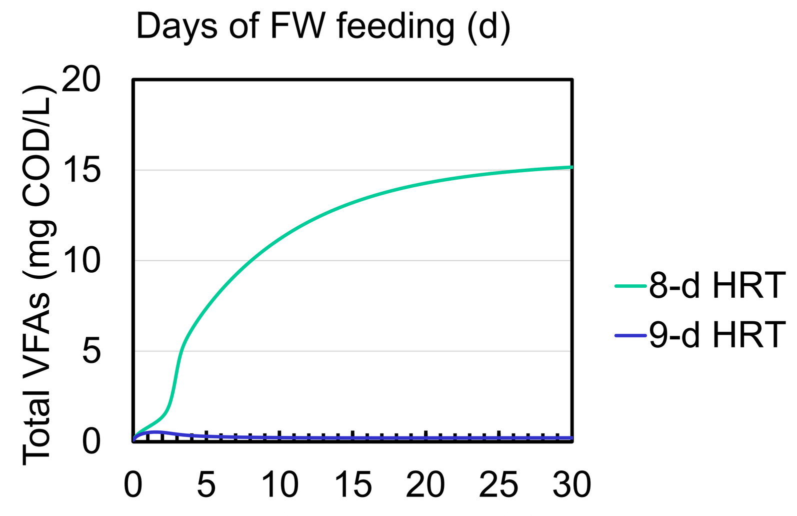
Parameters	Units	ThS feed	FW feed	Parameters	Units	ThS feed	FW feed
pH		6.55	5.20	**Sugar**	% of total SCOD	0	50
TCOD	g/L	50.3	200	**Amino acid**		0	50
SCOD	g/L	1.5	70	**Generic SCOD**		100	0
Total solid	g/L	43.2	31.6	**HCO_3^-**	mg $CaCO_3$/L	500	0
Volatile solid	g/L	34	30.9	**NH_4^+**	mg/L N	95	115
DO	mg/L	0	0	**Acetate**	mg/L	0	295
Carbohydrates	% of biodegradable particulates	23	41	**Propionate**	mg/L	0	219
Proteins		8	32	**Butyrate**	mg/L	0	43.5
Lipids		55	27	**Valerate**	mg/L	0	50.5
Generic PCOD		14	0				

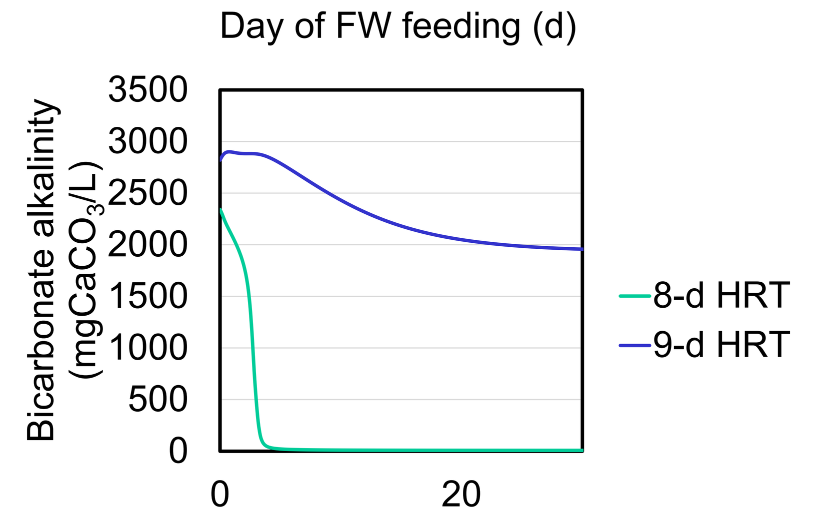
HRT and Reactor Stability at High Loadings

Simulations of continuously-fed digesters fed 200 g TCOD/L of FW shows stable performance as low as 9-d HRT based on pH. The 8-d HRT sours immediately due to the pH decreasing to below the inhibition level of methanogens (< 6.5), causing methanogens washout, VFAs accumulation and depletion of from HCO_3^- alkalinity.



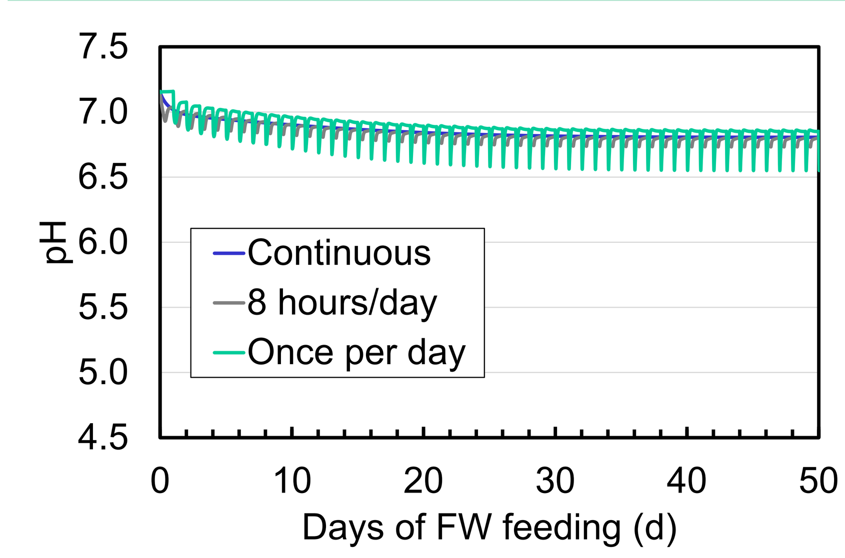


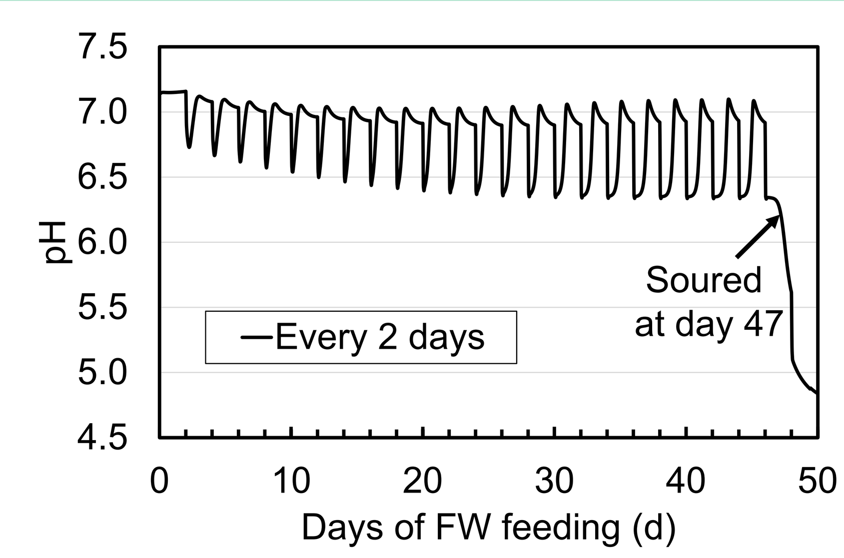




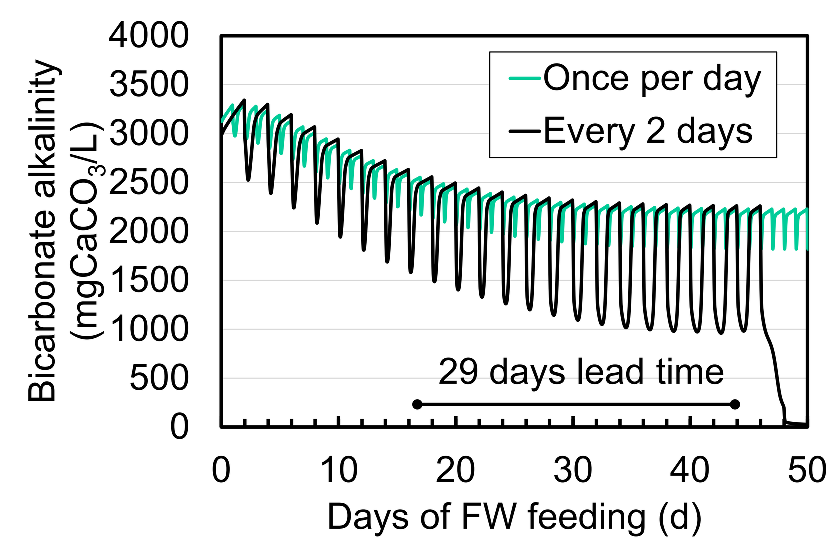
Feeding Frequency Significantly Impacts Digester Stability

We simulated digesters fed either continuous, continuous for 8 hours per day, instantaneously fed every day at the same time, or instantaneously fed every 2 days. Souring was observed when the digester was fed every 2-d instantaneously at an 18-d HRT.

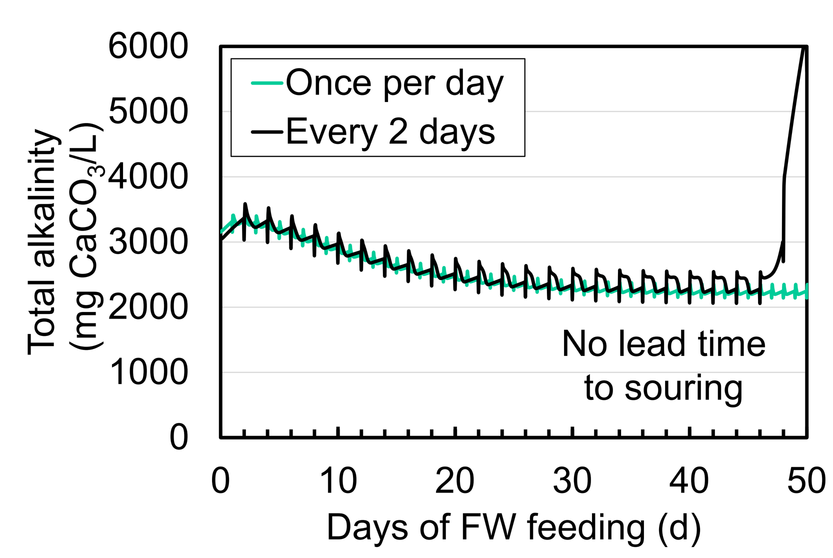


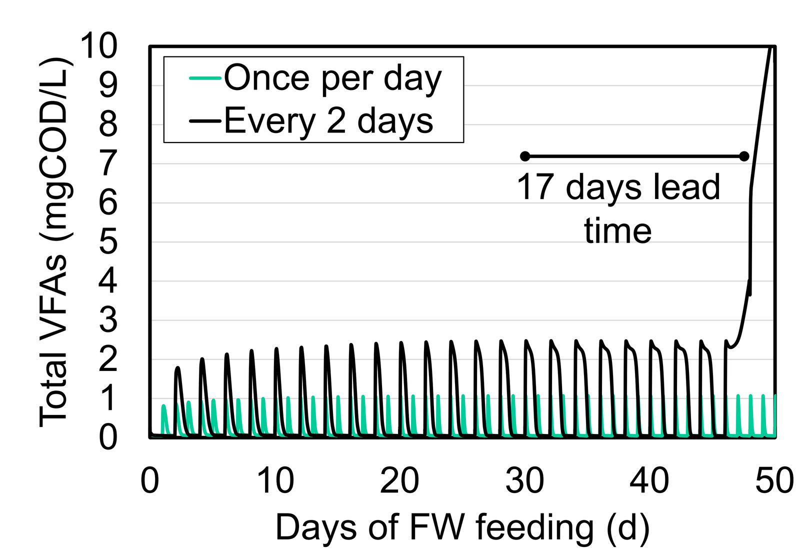


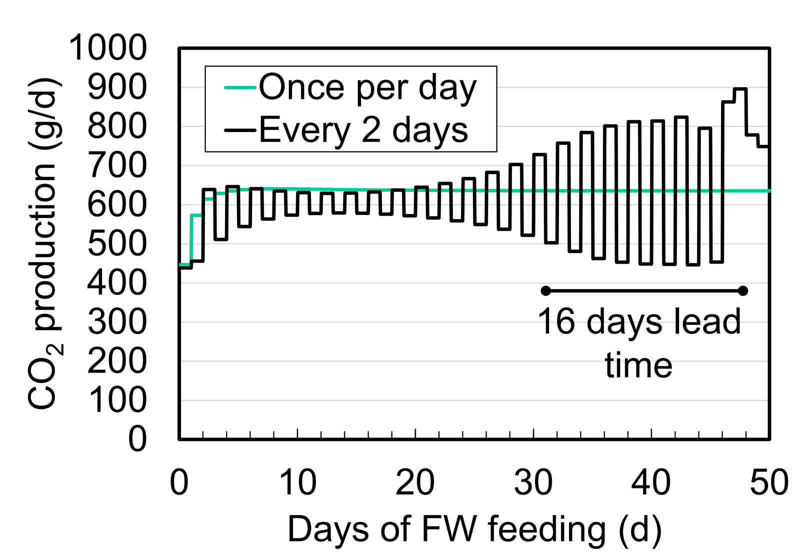
The digester fed every 2-d had longer term decrease in HCO_3^- alkalinity due to two phenomena related to pH: (1) longer accumulation of VFAs, especially acetate, when the pH temporarily decreased to < 6.5, inhibiting methanogenesis; and (2) CO_2 off-gassing as the pH decreased below the pK_a of H_2CO_3-HCO_3^- (pK_a = 6.35). Once HCO_3^- alkalinity decreased to < 1000 mg $CaCO_3$/L, there was insufficient buffering capacity to help the reactor recover to > pH 6.5.

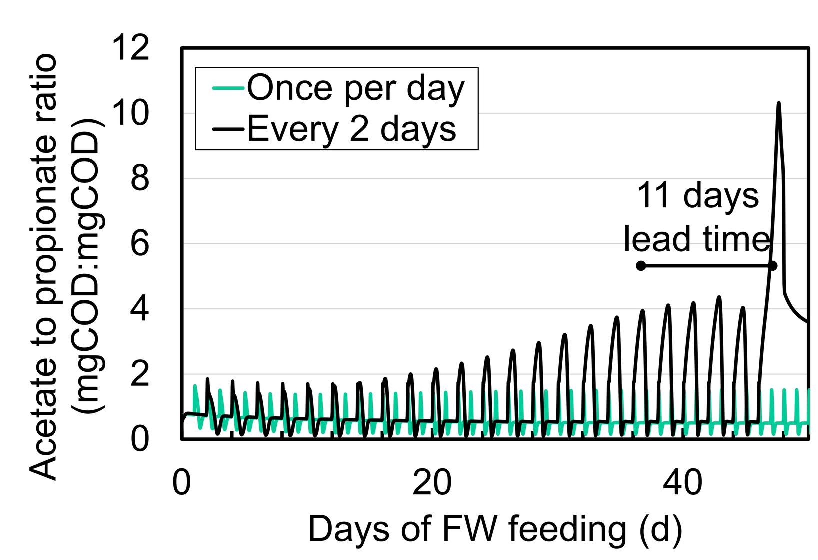


HCO_3^- alkalinity < 1500 mg $CaCO_3$/L is often cited as the lower threshold for safe operations of traditional anaerobic digesters[2]. Because the daily HCO_3^- fluctuates with intermittent feeding, this criteria is less applicable.









Leading indicators of souring: HCO_3^- was the indicator with the longest lead time. While HCO_3^- is difficult to quantify directly, it can be determined from the difference between total and VFA alkalinity. Ratios of VFA:SCOD, SCOD concentration, NH4+ concentration, and solids reduction did not indicate souring until pH decreased to < 6.0.

References: [1]U.S. EPA, (2018). Advanced Sustainable Materials Fact Sheet.
[2]G. Parkin and W. Owen, (1986). *Journal of Environmental Engineering*, 112(5), 867-920.

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