To Expand or Intensify? Chattanooga's Anaerobic Digestion Question

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The City of Chattanooga (city) currently processes primary and secondary solids through anaerobic digestion and lime stabilization, respectively. The city is evaluating simplified solids handling approaches that accommodate future growth, including conversion to full-plant mesophilic anaerobic digestion (MAD).

A pilot-scale study was conducted to assess the feasibility of using thermal hydrolysis pretreatment and intensified MAD to accommodate stabilization of future-year (2034) full-plant solids loads within the existing anaerobic digestion complex. Results from the study indicated that stable operation can be achieved at an intensified organic loading rate of 6.4 kg/m^3-d (0.4 lb/ft^3-d) when thermal hydrolysis pretreatment is applied, therefore reducing the need to build additional digester infrastructure. Secondary benefits were also observed, including increased volatile solids destruction and biogas production, Class A quality biosolids, and improved dewaterability.

The purpose of this article is to discuss the results of a pilot-scale demonstration study evaluating intensified anaerobic digestion through thermal hydrolysis pretreatment at the Moccasin Bend Wastewater Treatment Plant (MBWWTP), located in Chattanooga, Tenn.

Water resource recovery facilities (WRRFs) are undergoing a transformation from being traditionally focused on removing contaminants from wastewater to now recovering resources. Utilities are realizing the benefits of enhancing bioenergy, biosolids, water, and nutrient recovery and the value it brings to the overall bottom line for the end user.

As this paradigm shift drives the development of emerging technologies, any WRRF can participate in a circular economy that benefits the consumer by preserving and renewing water, energy, and material resources at the local level.

Anaerobic digestion is a key component in realizing a circular economy. It's well-documented that anaerobic digestion has the potential to generate more energy than it consumes. When anaerobic digestion is integrated with combined heat and power (CHP), or conversion of biogas to biomethane, it can deliver cost-effective, net-energy-neutral, or positive solutions for WRRFs. The feasibility and efficiency of anaerobic digestion can be further enhanced with pretreatment, such as a thermal hydrolysis process (THP), which enables intensified loading to digesters, resulting in increased digestion capacity and enhanced performance, such as increased volatile solids reduction (VSR). The increased VSR can yield other benefits, including Class A-quality biosolids, increased biogas production, improved dewaterability, and improved nutrient availability for subsequent recovery.

The THP was first applied to improve sludge dewaterability (Haug et al.,1978), but has since grown into a pretreatment alternative for intensified anaerobic digestion. The THP is the engineered application of temperature (160 to 165°C) and pressure (6 to 9 bar) to more-effectively disintegrate floc and lyse-wasted solids, which is the rate-limiting step in anaerobic digestion. The resulting lysed sludge product has lower viscosity and increased available volatile solids for digestion.

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Methodology

The MBWWTP receives and treats flows from the city and the surrounding region prior to discharge to the Tennessee River. The facility currently produces over 90 dry tons per day (dtpd) of solids, with a projected-year (2034) annual average solids production of 120 dtpd and maximum-month solids production of 150 dtpd. The plant sludge composition is approximately 60 percent primary and 40 percent secondary solids.

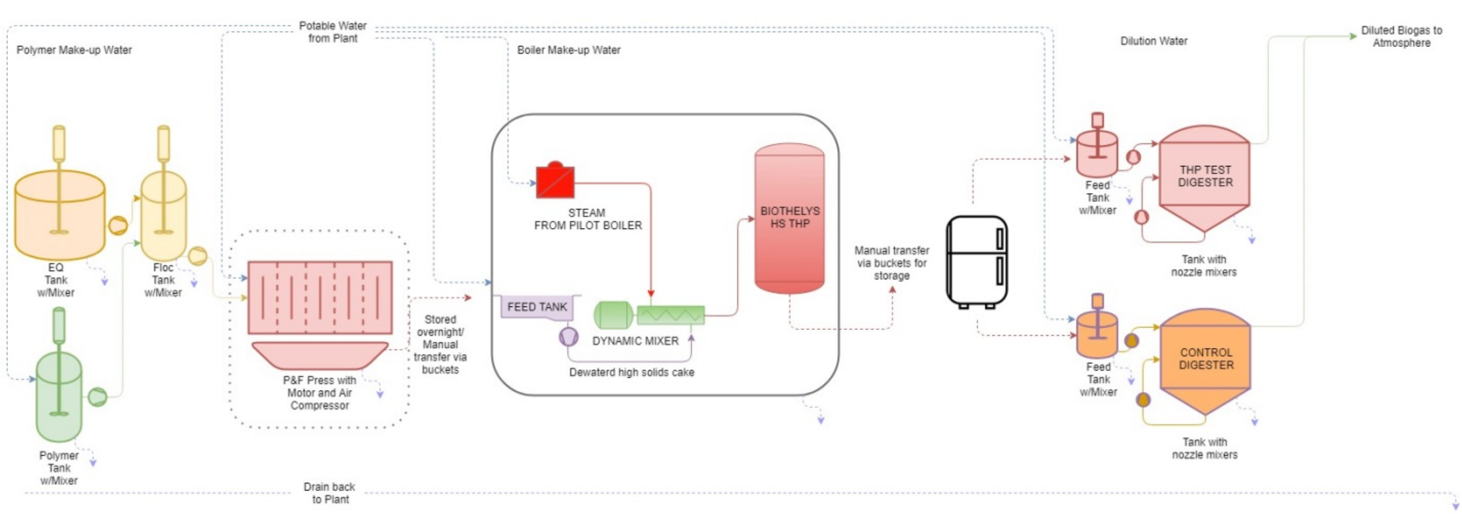

Figure 1. Pilot System Configuration

Approximately 47 dtpd of thickened primary sludge is stabilized via two-phase anaerobic digestion (2pad) and dewatered via centrifuges. Secondary waste activated sludge (WAS) is cosettled with the remaining primary sludge, stabilized through lime addition, and dewatered via vacuum-assisted plate and frame presses. The two biosolids products are then blended, resulting in an overall Class B product for beneficial use.

Given the increasing drivers for Class A biosolids and the industry trend toward resource recovery, the city identified a need to simplify the MBWWTP solids handling approach by implementing full-plant anaerobic digestion. The existing anaerobic digester complex consists of six 2.27-megaliter (Ml) digesters, which provide a combined working volume of 13.6 Ml. If no new digesters are added to accommodate future full-plant solids production, the facility will have to operate at a hydraulic retention time (HRT) of 10 days at an organic loading rate (OLR) of 7.3 kg/m^3-d (0.45 lb/cf-d).

Conventional digesters cannot operate at these high organic and hydraulic loading rates due to the following:

- Kinetic limitations in a completely mixed reactor
- Mixing energy required for highly viscous, high-solids sludge
- Rate-limiting steps (such as hydrolysis) inherent to the digestion process
- Ammonia toxicity

A minimum of 32.5 Ml of digester volume is therefore required to accommodate full-plant anaerobic digestion under year 2034 flows and conventional operating conditions. The project, however, hypothesized that THP pretreatment could address the challenges outlined and allow for intensified full-plant anaerobic digestion within the existing digester infrastructure. Such an approach would also result in Class A biosolids and the secondary benefits of increased biogas production and improvements to sludge dewaterability.

Previous studies have demonstrated that anaerobic digestion of high-strength manure can be sustained at over 2,000 mg/L total ammonia concentrations (Esquivel-Elizondo et al., 2016). A pilot-scale study was employed to demonstrate the practical application of this knowledge for domestic wastewater and to demonstrate the efficacy of THP pretreatment to improve digestibility while maintaining a high OLR.

Major components of the pilot-scale system included a prethickening plate and frame press to generate 22 percent solids prior to hydrolysis, a Bio Thelys™ high-solids THP system with a dynamic mixer, and two 740-liter anaerobic digesters (Figure 1). Three test phases were conducted simulating increasing OLRs to a test digester, with a target maximum OLR of 7.3 kg/m^3-d (0.45 lb/cf-d). A control digester was operated at OLRs consistent with standard MAD practices.

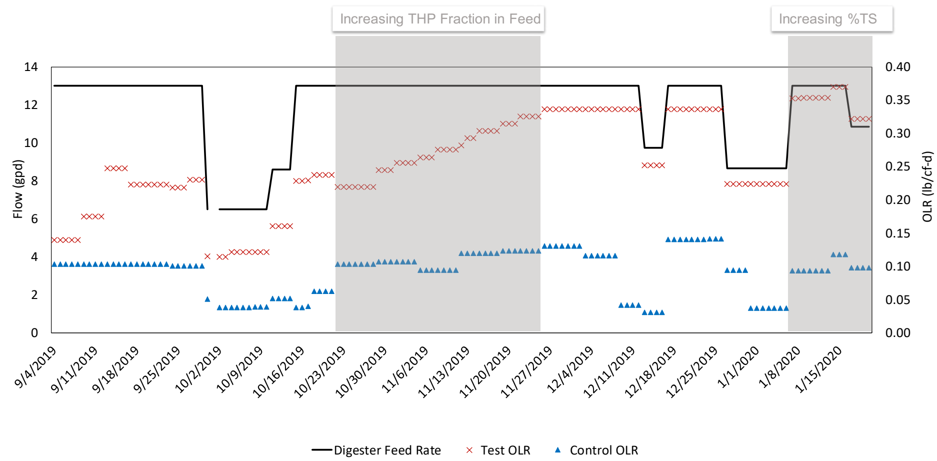

Figure 2. Pilot Digesters Volumetric Loading Rate and Organic Loading Rate

Table 1. Summary of Pilot-Derived Inputs

System	Parameter	Units	Conventional Anaerobic Digestion	Partial-Plant THP	Full-Plant THP	Source
Thickening	Pre-Thickening Polymer Demand	lb/dt	6	15	15	Pilot, Vendor Testing
	Pre-Thickening Maximum TS	%TS	25	25	30	Pilot, Vendor Testing
Digestion	Maximum Feed Solids	%TS	6	12	12	Pilot + Industry Experience
	Maximum OLR	lb-VS/cf-day	0.20	0.40	0.40	Pilot + Literature
	Minimum HRT	days	15	10	10	Pilot + Industry Experience
	Average VSR	% reduction	57	62	65	Pilot + MWRD + Literature
Biogas	Biogas Yield	cf/lb-VS destroyed	15	15	15	Literature
	Methane Content	% CH_4	60	60	60	Pilot
Dewatering	Dewatering Polymer Demand	lb/dt	30	40	40	Pilot, Vendor Testing
	Dewatering Maximum TS	%TS	30	34	36	Pilot, Vendor Testing
Sidestream	sCOD	mg/L	1,500	-	9,500	Pilot
	Ammonia	mg/L	585	-	1,800	Pilot
	Orthophosphate	mg/L	115	-	375	Pilot
Biosolids	Biosolids Quality	Class	B	B	A	Pilot

Digester stability and the acclimation of archaea and bacteria to high concentrations of ammonia in the intensified test digester were closely monitored. Test and control digester performance were compared in terms of organic and hydraulic loading rates, VSR, biogas production, and dewaterability of the resulting digestate. The project also considered the Bio Thelys dynamic mixer's ability to provide more-efficient steam delivery and rapid condensation for improved lysis relative to other commercially available THP systems.

Data from the study were used to inform a business-case evaluation comparing the capital and annual operating expenditures required to expand the MBWWTP anaerobic digester complex to accommodate future full-plant solids production, or intensify solids stabilization within the existing anaerobic digester footprint through addition of high-solids thermal hydrolysis pretreatment.

Results

The volumetric loading and organic loading rates administered to each digester during the pilot period are shown in Figure 2. Construction activities at the gravity thickener complexes and pipe tap clogging prohibited consistent sludge collection through the testing period, most significantly during the first month of operation. The control OLR also varied slightly over the testing period as a result of inconsistent total solids concentrations in gravity thickener underflows. The fraction of hydrolyzed sludge in the test

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Table 2. Business-Case Evaluation Conceptual Design Criteria

Parameter	Units	Alt 1 New Dig	Alt 2 Partial THP	Alt 3 Full THP
Prethickening target	%TS	8 – 10%	16%	22%
THP Capacity	dtpd	N/A	90	143
Digester feed TS (min)	%TS	6%	8%	8%
Digester feed VS (average)	%VS	79%	79%	79%
Digester hydraulic load	gpd	470,000	430,000	430,000
Digester HRT (min)	days	15	12	12
Digester OLR (max)	lb/cf-d	0.15 – 0.18	0.34	0.35
Digester operating temperature	degC	35	35	35
Digester VSR	%	57	62	65

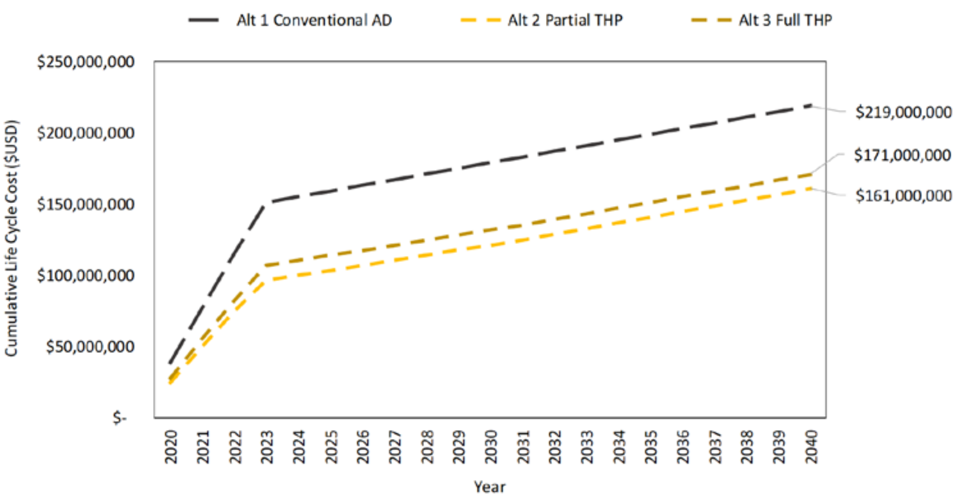

Figure 3. Cumulative Life Cycle Cost

Table 3. Weighted Qualitative Comparison of Alternatives

Category	Weight	Alternative 1 Conventional Anaerobic Digestion	Alternative 2 Partial-Plant THP	Alternative 3 Full-Plant THP
Capital Cost	25%	3	1	2
O&M Cost	20%	2	2	2
Energy Use/ Production	5%	3	2	1
Mass/Volume Reduction	5%	3	2	1
Biosolids Beneficial Reuse (Class A vs Class B)	15%	3	3	1
Operational Complexity	5%	1	3	2
Reliability	5%	3	2	1
Impact to Other Unit Processes	5%	1	2	3
Footprint	5%	1	3	3
Construction Feasibility/ Sequencing	5%	1	2	1
Environmental Impact	5%	3	2	1
Total Weighted Score		**2.40**	**2.00**	**1.70**

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digester feed stream was gradually increased by approximately 5 to 10 percent per week to allow the test digester to properly acclimate.

Toward the end of the testing period, the organic loading rate was increased to a maximum of 5.6 kg/m^3-d (0.37 lb/cf-d) by increasing the total solids concentration of the hydrolyzed feed sludge from 10 to 12 percent.

Key data obtained from the pilot evaluation are summarized in Table 1. A partial THP condition was not tested at the MBWWTP; therefore, several parameters needed for the business-case evaluation were informed by previous THP piloting efforts by the Metro Wastewater Reclamation District.

A business-case evaluation was developed concurrently with piloting efforts, beginning with an assessment of future flow and load conditions and existing digester capacity. Key design criteria used to inform the digester capacity evaluation is summarized in Table 2.

The three alternatives evaluated, and their key scope items, are also described. Capital costs were estimated for each alternative using a Class 5 opinion of probable construction costs; escalation, engineering, and administrative costs were added to derive a total project cost estimate. Annual operations and maintenance costs were also estimated for each alternative based on year 2030 annual average flow and load conditions. The cumulative annual net present cost of each alternative was calculated and is presented in Figure 3.

Alternative 1: WAS Thickening Improvements + New Digester Complex

- Construct a new WAS thickening facility to ensure a minimum blended raw sludge concentration of 6 percent total solids (TS).
- Construct a new MAD complex consisting of six digesters, with sufficient capacity to treat year 2034 flows and loads with one digester out of service.
- Maintain the existing anaerobic digestion complex for future treatment.

Alternative 2: New Prethickening + Partial-Plant THP

- Construct a new prethickening facility for 60 percent of the solids load.
- Construct a new partial-plant THP facility, including steam generation and sludge cooling.
- Expand the existing digester complex to include two new MADs providing sufficient capacity to treat year 2034 flows and loads with one digester out of service.
- Replace the digester gas handling system.

Alternative 3: New Prethickening + Full-Plant THP

- Construct a new prethickening facility for 100 percent of the solids load.

- Construct a new full-plant THP facility, including steam generation and sludge cooling.
- Expand the existing digester complex to include two new MADs providing sufficient capacity to treat year 2034 flows and loads with one digester out of service.
- Replace the digester gas handling system.

Discussion

While the annual operating costs associated with Alternative 1 were estimated to be approximately 16 percent lower than that of Alternatives 2 and 3, the significant capital investment required to construct an entirely new and properly sized digester complex resulted in a higher overall net present cost. Furthermore, the city is interested in pursuing energy recovery alternatives, such as combined heat and power or generating renewable natural gas.

Incorporating such improvements into the evaluation would result in more-favorable annual operating costs for the THP options, as there is a significant increase in biogas production with THP.

Another key consideration was the impact to the dewatering sidestream and whether additional treatment is necessary to ensure that the higher-strength centrate does not adversely affect the facility's ability to meet effluent ammonia limits. Pilot testing showed that the concentration of ammonia in centrate is expected to increase by a factor of five for Alternative 1 and 15 for Alternatives 2 and 3. Given the historic secondary treatment performance, the city is not expected to be able to accommodate the increased ammonia loads; therefore, a sidestream deammonification was recommended. For planning purposes, the ANITA™Mox moving bed bioreactor system was assumed for Alternative 1 and the integrated fixed-film activated sludge system was assumed for Alternatives 2 and 3.

A qualitative comparison was also performed by collaboratively weighting evaluation categories and scoring each alternative to capture the city's priorities. Results are presented in Table 3 and indicate that the full-plant THP alternative is the most favorable. This is primarily due to the alternative's ability to produce Class A biosolids, where Alternatives 1 and 2 will not.

Conclusion

The pilot study successfully demonstrated stable MAD operation with intensified organic loading rates and thermal hydrolysis pretreatment. Data from the study were used to inform a business-case evaluation, which concluded that such intensified operation would allow the MBWWTP to leverage existing digester capacity to treat future flows and loads, while minimizing capital expenditure. Secondary operational benefits were also observed, including increased volatile solids destruction and biogas production, Class A quality biosolids, and improved dewaterability, which resulted in a more-favorable net present cost.

References

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