Reinventing Your Biosolids Management Program and Unlocking Resource Recovery with Thermal Hydrolysis – The City of Raleigh’s Journey

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ABSTRACT

The City of Raleigh operates the Neuse River Resource Recovery Facility (NRRRF), a 75 MGD (11.83 ML/hr) capacity advanced nutrient removal treatment facility. The treatment facility includes primary and advanced secondary treatment coupled with tertiary filtration to produce a high-quality effluent with typical effluent total nitrogen concentrations less than 3.0 mg TN/L. Residuals generated during the treatment process are currently managed via a range of product streams with different characteristics and different levels of stabilization.

During its most recent residuals masterplanning cycle the City adopted a course of action which will consolidate a variety of residuals stabilization processes into a single stabilization process utilizing thermal hydrolysis pre-treatment (THP) coupled with mesophilic anaerobic digestion. Following the masterplanning process, the City of Raleigh retained an engineering team to develop the recommended masterplan concept into a Preliminary Engineering Report (PER) and is currently underway with detailed design activities with project delivery using a Construction Manager at Risk (CMAR) delivery method.

This paper presents the approach to, and results of, the concept development advanced through the preliminary engineering report phase of the work. Major facilities evaluated in the PER and currently under detailed design include:

- Fats, Oils and Grease (FOG) Receiving and Handling
- Secondary Sludge Thickening Improvement
- Blended Sludge Screening and Pre-Dewatering
- Thermal Hydrolysis Pretreatment and Mesophilic Anaerobic Digestion
- Post-Dewatering System Improvements
- Sidestream Nitrogen Removal via ANAMOX bacteria

This paper shares the City of Raleigh’s journey to reinvent its biosolids management program by applying a THP and anaerobic digestion process to produce on-site a Class A biosolids product from all of its residuals.
Background

The City of Raleigh operates the Neuse River Resource Recovery Facility (NRRRF), a 75 MGD (11.83 ML/hr) capacity advanced nutrient removal treatment facility, which serves most of the municipalities located in the eastern half of Wake County, North Carolina in the rapidly growing Research Triangle Park metropolitan area. The treatment facility includes primary and advanced secondary treatment coupled with tertiary filtration to produce a high-quality effluent with typical total nitrogen concentrations less than 3.0 mg TN/L suitable for direct discharge to the Neuse River or for utilization as a high quality reuse water through a growing reuse program. Residuals generated during the treatment process are currently managed by the City in a variety of outlet streams, including:

- Alkaline Stabilization to Class A and marketing and distribution as “RaleighPlus”
- Off-Site Contract Composting of dewatered unstabilized cake
- Off-Site Class B Liquid Land Application of aerobically-stabilized residuals
- On-Site Class B Liquid Land Application of aerobically-stabilized residuals

The City has had a long term interest in environmental stewardship and resource recovery and has been a long-term participant in the National Biosolids Partnership’s Environmental Management Program as a Platinum Certified Member since December 2006. As a part of their NBP-EMS program the City had conducted a residual management masterplan study in 2008 with a subsequent update in 2013. The 2008 masterplan evaluated a number of management technologies and approaches and recommended upgrading the management program to include mesophilic anaerobic digestion and thermal drying to produce a Class A product stream. However, economic considerations immediately following completion of the 2008 plan resulted in a delay in implementation of the concept and resulted in a desire to update the masterplan in 2013 to affirm, or change, decisions developed and recommended in the 2008 plan.

The 2008 masterplan evaluated the thermal hydrolysis pretreatment (THP) process and classified it as an emerging technology for biosolids management. The 2013 masterplan update; however, acknowledged the continued development and commercialization of the THP process over the intervening five-years and recommended that the anaerobic digestion process be coupled with THP to produce a Class A product. Drying was considered as a “follow-on” process in the 2013 masterplan for additional mass reduction and for the production of a differentiated product stream for marketing and distribution. Following the 2013 masterplan update the City of Raleigh retained an engineering team to develop the recommended masterplan concept into a Preliminary Engineering Report (PER) with a plan to move the project into detailed design, construction, and ultimately into commissioning.

The following sections of the paper will present the approach to, and results of, the concept development as it has advanced through the preliminary engineering report phases and initial detailed design phases of the work. The facilities envisioned as part of the City of Raleigh’s BioEnergy Recovery Program (BERP) are planned to be delivered in at least two phases. The first phase of improvements will provide infrastructure to support current plant design loadings (75 MGD / 11.83ML/hr) and a second phase will ultimately expand capacity to meet design loading rates associated with 90-MGD (14.20 ML/hr), the plant’s 2035 expected volumetric permitted flow capacity.
BioEnergy Recovery Program Facility Description

The major facilities recommended in the PER to be constructed as part of the BERP include:

- Fats, Oils and Grease (FOG) Receiving and Handling
- Secondary Sludge Thickening Improvements
- Blended Sludge Screening and Pre-Dewatering
- Thermal Hydrolysis Pretreatment and Mesophilic Anaerobic Digestion
- Post-Dewatering System Improvements
- Sidestream Nitrogen Removal via ANAMOX bacteria
- Digester Gas Treatment and Utilization

The general process flow arrangement for the major facilities are shown in Figure 1. The major unit process components envisioned are described in greater detail below.

Figure 1 – BERP Process Flow Schematic

The general facility arrangement and conceptual layout rendering on the NRRRF site is shown in Figure 2.
A market analysis study was conducted to estimate the quantity of grease interceptor waste (GIW), commonly referred to as “FOG”, in the plant’s Wake County service area and typical tipping and receiving costs that haulers in the region were paying for handling and disposal. Estimates were developed using several methods including: (1) service area population and (2) service area food service. Based on the market analysis a decision was made to include provision for receiving up to 420,000
gallons per week spread across six (6) delivery days with continuous seven (7) day per week addition to the digestion process.

The GIW/FOG receiving station will include two unloading connections with material routed through rock traps and screening prior to delivery to a GIW/FOG receiving wet well. The wet well included chopper pumps for both mixing and transfer service. The GIW/FOG will not be routed directly to the THP unit process but will enter the digestion process downstream as a pasteurized material using the 40 CFR 503 time and temperature provisions to achieve pasteurization. The pasteurization process will use multiple batch reactors operating in a fill-heat-hold-drain configuration. Pasteurized GIW/FOG will be routed to storage tankage for continuous feed to the anaerobic digester unit process.

A preliminary general arrangement rendering for the full facility is shown in Figure 3. The receiving station will include two screening and handling units discharging to a receiving wet well equipped with dual chopper pumps for both mixing service and for transfer of received materials to the downstream pasteurization tanks. Initially four pasteurization reactor vessels will be provided with the ability to expand the facility to include two (total of six) reactors. Following batch pasteurization the material will be routed to two large volume storage tanks from which the pasteurized material will be feed to the anaerobic digester tanks. Full system containment will be provided for the receiving, pasteurization, and storage tank areas.

Figure 3. – FOG Receiving and Pasteurization System Layout
Enlarged renderings of the pasteurization system and the storage tankage are shown respectively in Figure 4 and Figure 5.

Figure 4. – FOG Receiving and Pasteurization – Pasteurization Tanks

Figure 5. – FOG Receiving and Pasteurization – Storage Tankage
Secondary Sludge Thickening Improvements

Waste activated sludge (WAS) will be thickened upstream of the screening and pre-dewatering unit process using gravity belt thickening (GBT) unit process equipment. The existing GBT building includes three (3) two meter (2.0-m) GBT thickening units. The envisioned upgrades will include installation of a fourth GBT in an open slot in the thickening room. The upgrade to the thickening unit process will also include replacement of GBT feed pumps, upgrade to the polymer preparation and feed equipment and miscellaneous improvements for the piping and valving to provide for improved process control.

Blended Sludge Screening and Pre-Dewatering

Thickened waste activated sludge (TWAS) will be blended with primary sludge (PS) in a new Screening and Pre-Dewatering Building to be constructed on the plant site. This process building will include the following:

- **Blended Sludge Storage** – Three storage reactors with approximately 60,000 gallons working volume to be used for receiving and blending TWAS and PS upstream of screening and dewatering. These storage tanks will be fully mixed using vertical mixing equipment. This storage volume will be initially sized to meet future Phase II throughput demands.
- **Screening** – The Phase I improvements will include four (4) sludge screens with provision for adding two (2) more units with the Phase II expansion. These screening units will removed debris and materials greater than 5-mm in size to protect the downstream THP system equipment following dewatering. Screenings will be collected in containers and hauled to a local landfill for disposal.
- **Screened Sludge Storage** – Three (3) storage reactors similar in size and configuration to the blended sludge storage reactors will be provided to decouple the screening and the dewatering processes and provide additional dampening in the system upstream of the THP treatment process.
- **Pre-Dewatering** – The Phase I improvements will include three (3) horizontal decanter centrifuges each with a dewatering capacity of 4,000 dry pounds per hour. Provision will be made to expand the pre-dewatering capacity under Phase II by adding two (2) additional horizontal decanter centrifuges. An overhead bridge crane will be provided for equipment maintenance.
- **Dewatered cake storage** will be provided by relocation of two existing dewatered cake sludge storage hoppers. The THP feed pumps will be located integral with the bulk dewatered cake storage facility and provisions are also made for truck loadout from the pre-dewatering building to meet plant sludge disposal needs when the THP system would be out of service for its annual maintenance inspection.
- **Polymer Storage and Conditioning** – The Phase I improvements will include two (2) bulk neat polymer storage tanks and associated mixing and neat polymer make-up equipment. Provision will be made in the facility layout for up to two (2) additional bulk neat polymer storage tanks.
- **Building Support Systems** – This facility will also include spaces for men’s and women’s bathrooms and locker facilities, a control room, a wet lab space, and mechanical and electrical rooms.
Renderings of the intended facilities are shown as follows:

- Figure 6. Screening and Dewatering Building 3-D Rendering
- Figure 7. Screening and Dewatering Building – Upper Floor
- Figure 8. Screening and Dewatering Building – Lower Floor
Thermal Hydrolysis Pretreatment and Mesophilic Anaerobic Digestion (THP+MAD)

The Phase I thermal hydrolysis pretreatment (THP) process initially have a design throughput capacity of 184,000 dry pounds per day (83,600 kg per day) at 16.5% feed solids content. Provision will be made in the design and general arrangement for the ultimate addition of a second THP treatment train in the Phase II facility expansion. Key elements of the THP+MAD system include:

- **THP Reactor Process** – During the PER process preliminary sizing and design was developed around the CAMBI B6-4 reactor system and the Kruger BIOTHELYS batch reactor treatment systems. Following completion of the PER and during the early detailed design development the City decided to move forward with the design based on the CAMBI B6-4 reactor system.

- **Post THP Cooling** – Cooling of the post-THP hydrolyzed sludge is accomplished initially by dilution of the post-THP sludge, which has a concentration of 13.5% to 14.0% based on condensed steam water mass, to a digester feed concentration in the 9.5% to 10.5% range required to manage digester ammonia concentrations. Following this initial dilution, which will cool the post-THP sludge from approximately 220°F (105°C) to about 170°F to 160°F (75°C to 70°C), supplemental cooling will be required to maintain anaerobic digester temperature in the 104°F (40°C) range. Final cooling will be provided by a tube-in-tube heat exchanger provided as part of a digested sludge recirculation loop to maintain velocity in the heat exchanger.

- **Anaerobic Digestion** – The Phase I anaerobic digestion system consists of two (2) anaerobic digesters with a nominal straight shell operating volume of 2.1 million gallons (17.5 ML). These digester tanks will be provided with fixed covers and pumped mixing systems and be designed to operate at a fixed volumetric overflow level with special provisions to accommodate storage of up to 10% volume inside the tank for rapid volume expansion in addition to being provided with an emergency overflow for volume expansion beyond this amount.
• Digester Control Building – A digester control building is provided with will house the mixing pumps, recirculation and the transfer pumps. Full redundancy is provided for the mixing pumps with an installed spare pump provided for each of the two digester tanks. Recirculation pumps are provided to support the digester cooling system recirculation loop. Transfer pumps are provided to move digested sludge from the anaerobic digester complex to the digested sludge storage tanks immediately upstream of final dewatering.

Renderings of the THP and anaerobic digestion system are shown in the following:

• Figure 9. Anaerobic Digester Typical Configuration
• Figure 10. Digester Complex Layout
• Figure 11. Digester Control Building General Arrangement

Figure 9. – Anaerobic Digester Typical Configuration
Figure 10. – Digester Complex Layout

Figure 11. – Digester Control Building General Arrangement
Post-Dewatering System Improvements

The Neuse River RRF has three 2.0-meter belt filter presses (BFP) and one 650-mm nominal diameter dewatering centrifuge (DCEN) which prior to the upgrades were utilized to produce a dewatered cake for downstream on-site alkaline stabilization or for off-site composting by a 3rd party service provider. The improvements required to accommodate a transition to the post-THP Class A dewatering service include:

- **Digested Sludge Storage Tanks** – The two existing aerated and pumped mixed sludge storage tanks upstream of dewatering will be retained in service. The aeration system will be retained; however, it is not normally intended to operate on the anaerobically digested sludge and mixing will be provided by the pumped jet mixing system. Minor work will be completed on these tanks for rehabilitation of the geodesic dome covers.

- **Dewatering Unit Feed Pumping** – Feed pumping to the current BFP and DCEN units is provided by progressing cavity pumps sized to provide a feed rate to the downstream dewatering units of up to 300-gallons per minute at a typical feed solids concentration of 2.0%. However, the post-THP residuals concentration is expected to be in the 4.5% to 5.5% total solids range making the existing pumps oversized for feeding the dewatering equipment. These existing pumps will be replaced with smaller volumetric capacity pumps to provide for a mass feed rate to the BFP dewatering equipment of up to 2,500 dry pounds per hour (1,140 kg/hour) and to the DCEN equipment of up to 3,000 dry pounds per hour (1,360 kg/hour).

- **Pre-Dewatering Dilution Water** - Post-feed pumping dilution capacity to support a 1:1 dilution will be provided as part of the improvements. The dilution water will serve to reduce the feed concentration to the dewatering units to 2.25% to 2.75% for enhanced polymer dispersion during conditioning and also to provide dilution to meet sidestream treatment conditioning requirements.

- **Belt Filter Press Dewatering** – The existing belt filter press dewatering equipment is nearing the end of its useful life (> 20 years age) and will be replaced as part of this project. The existing BFP equipment has eight (8) pressure rolls; however the replacement dewatering equipment will be provided with twelve (12) pressure rolls for enhanced dewatering of the post-THP anaerobically digested sludge. Special provision will be made on the BFP dewatering units to separate filtrate from the washwater. Filtrate will be collected and routed to sidestream treatment and washwater will be routed back to the plant headworks through the plant drain system.

- **Centrifuge Dewatering** – The existing DCEN unit was installed less than 10-years ago and will continue in operational service. Minor piping modifications will be required to route the centrate to the sidestream treatment system. Furthermore, downstream screw conveyance equipment will be replaced with a belt conveyor to integrate with the other dewatered cake conveyance system modifications.

- **Dewatered Cake Storage** - The existing dewatered cake storage bins utilized to support the off-site composting operation will be relocated as part of this project and repurposed for wet cake receiving from the pre-dewatering process and used to support the THP feed pumping system.

These improvements leverage the plant’s existing asset base by making use of the current dewatering building and significant portions of the conveyance and post-dewatering covered cake storage area.
Sidestream Treatment Improvements

Several sidestream treatment alternatives were evaluated during the PER phase of the project, including:

- **Base Case** – This option would have returned the nitrogen and phosphorus rich final dewatering filtrate to the plant headworks with minimum nutrient removal and/or recovery processing. This established the economic baseline upon which the other sidestream treatment alternatives would be assessed. Phosphorus removal for the base case would utilize chemical phosphorus removal to achieve effluent total phosphorus limits. Nitrogen removal for the base case would use a 4-stage BNR activated sludge process coupled with deep bed denitrification filters with supplemental carbon addition.

- **Phosphorus Removal Only Option** – In lieu of chemical phosphorus removal in the mainstream this alternative evaluated using a struvite recovery technology to create a marketable fertilizer product. The nitrogen removal under this alternative remained in the mainstream treatment process.

- **Nitrogen Removal Only Option** – In lieu of mainstream nitrification and denitrification this alternative evaluated utilizing deammonification for sidestream nitrogen removal. Several different vendor furnished technologies were considered as part of the evaluation. The phosphorus removal under this alternative remained chemical addition in the mainstream treatment process.

- **Nitrogen and Phosphorus Removal Option** – This option coupled the struvite recovery and deammonification processes into a combined sidestream treatment approach for both phosphorus and nitrogen removal.

The recommended option retains chemical phosphorus removal as the selected alternative; however, provisions have been made in the process flow and site layout to convert to struvite harvesting and recovery should economic and/or regulatory conditions support a treatment technology transition. The nitrogen removal approach recommended was to provide deammonification to the sidestream from the final dewatering process. Several technology approaches will be further developed during the detailed design phase to the 30% design level at which point a final technology selection will be made for implementation as part of the overall Phase I improvements project.

**Digester Gas Treatment and Utilization**

Multiple options for digester gas utilization were evaluated during the PER phase of the project. All options included low pressure digester gas storage using ground level dual membrane gas storage coupled with fixed cover anaerobic digestion and digester gas utilization for THP process steam generation. Excess digester gas from the stabilization process was evaluated with options ranging from waste gas flaring (no energy recovery), on-site electrical generation without heat recovery, full on-site combined heat and power, cleaning for municipal fleet vehicle fuel, and cleaning for pipeline injection as a renewable natural gas (rNG) resource. These alternatives, and the associated economic analysis, are more fully described in Knight, et. al. (WEFRBC, 2017). The final selected alternative includes cleaning gas to pipeline injection quality and utilizing the natural gas pipeline to transport the rNG resource to a fleet fueling station for use in municipal vehicles with surplus rNG to be marketed to others as a vehicle biofuel.
The preliminary general arrangement drawing, excluding the final digester gas treatment train, is shown in Figure 12. During the PER phase several gas cleaning train approaches were evaluated for hydrogen sulfide, moisture, particulate, siloxane and carbon dioxide removal. Final selection of the gas cleaning train system, not shown in Figure 12, will be completed during the final design phase based on site visits, additional technology assessment and improved costing and economic analysis of total lifecycle costs including capital and operational and maintenance costs.

![Figure 12. – Digester Gas Storage and Boiler Building General Arrangement](image)

Current plans are to utilize pipeline natural gas for firing the steam boilers to support the THP system. Federal renewable fuel standard requirements (40 CFR Part 80, Subpart M – Renewable Fuel Standard) allow biogas generated from wastewater treatment to qualify as a cellulosic biofuel (Category 3 D-Code) which makes this fuel stream eligible to generate a marketable RIN (Renewable Identification Number) as part of its production. To the extent that a marketable RIN can be generated this provides and avenue for the City of Raleigh to further monetize the benefits associated with production of the rNG product. Therefore, the highest economic benefit for the city can be realized by purchasing pipeline NG for firing the steam boilers and maximizing production of rNG from the digester’s biogas.

A preliminary general arrangement of the boiler building is shown in Figure 13. Two boilers, a duty and standby, will be installed as part of the Phase I improvements. As shown, provision has been made in the layout for the future addition of a third boiler to accommodate increased steam demands from the Phase II improvements which will add a second THP train to the plant’s overall processing capacity. Additional systems in the boiler building include boiler water softening and treatment in addition to de-aeration and boiler feed water pumping. The boiler building also serves as an electrical distribution hub for the digester gas cleaning and associated equipment located in this quadrant of the overall plant facilities.
Energy Management Considerations

The recommended facilities to be installed under the Phase I improvements will result in a net energy positive operation when operating at their design loading rates as summarized in Figure 14. The resultant high level energy balance is summarized as follows:

**Digester Gas Energy Production & Consumption**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Digester Gas Energy Production</td>
<td>11.08 MW</td>
</tr>
<tr>
<td>Digester Gas Boiler Steam Input Energy for THP and FOG</td>
<td>-4.34 MW</td>
</tr>
<tr>
<td>Net Digester Gas Energy Production (after steam)</td>
<td>6.74 MW</td>
</tr>
<tr>
<td>Electrical Energy Utilized for Treatment</td>
<td>-4.62 MW</td>
</tr>
<tr>
<td><strong>Net Energy Balance (Production – Consumption)</strong></td>
<td><strong>2.12 MW</strong></td>
</tr>
</tbody>
</table>

The ability of the project to clearly demonstrate a net energy production allowed the City of Raleigh to secure a commitment from the North Carolina Division of Water Infrastructure’s Clean Water Revolving Loan Fund (CWRLF) as a “Green Project” for partial funding of the anticipated $80MM to $100MM facility capital cost. The $50MM CWRLF commitment as a Green Project allows the City of partially finance the anticipated improvements with a 0% interest 20-year loan with a resultant net present worth cost savings of approximately $13MM over a conventional 30-year duration bond financing project.
The City of Raleigh is currently in the detailed design phase for the improvement project described in this paper. Several significant milestones have been achieved since the completion of the PER, including:

- **Project Delivery Method** – Several delivery approaches were considered for the project including conventional design-bid-build, progressive design-build, and construction manager at risk (CMAR). Ultimately the City selected to deliver the project using the CMAR method and has completed the selection of a CMAR for the project who is now working with the detailed design team to finalize the construction documents.

- **Thermal Hydrolysis Technology Supplier** – Both the CAMBI and BIOTHLYS systems were carried through the PER development phase. Since completion of the PER phase the City has selected CAMBI as the system supplier for the THP system.

- **Preliminary Design Document Preparation** – The detailed design team has completed the 30% design documents for the project and submitted them for review and comment by both the City and the CMAR. The CMAR will be providing a preliminary opinion of probable construction cost based on the 30% documents for financial planning purposes and to guide decisions as the project documents move toward completion.

- **HAZOP Study and Workshop** – A HAZOP study was completed on the 30% design documents for each of the major treatment processes associated with the Phase I improvements and findings.
from the HAZOP are being incorporated into the final design for enhanced process safety and control.

The current project schedule is to complete detailed design activities during 2017 with the project moving into construction during 2018.

References