TWO-PHASE ANAEROBIC DIGESTION FOR CLASS A BIOSOLIDS AT MOCCASIN BEND WWTP

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ABSTRACT

The Moccasin Bend Wastewater Treatment Plant (WWTP) provides treatment for the City of Chattanooga, Tennessee and the surrounding region. The City has completed upgrades to the solids handling facilities to treat and dewater the primary solids and waste activated sludge (WAS) from the WWTP. This paper summarizes the process to handle the primary solids and the start-up process. Primary solids digestion is designed to handle approximately 47 dry tons per day.

After thickening, the primary solids are digested in a two-phase anaerobic digestion process prior to dewatering through centrifuges. The first phase is thermophilic digestion at temperature of 135º F to 140º F followed by mesophilic digestion at 95º F. Mixing is accomplished by Cannon® gas bubble mixers, six per digester. Liquid-ring gas compressors draw biogas from the digesters and provide mixing via large gas bubbles through the Cannon® mixers. Heating is provided by redundant boilers to provide hot water to heat solids-to-water heat exchangers. Total cost for the primary solids digestion system was approximately $12.4 million including equipment procurement and installation contracts. The process is designed to produce Class A biosolids as defined by US EPA regulations (EPA 1993).

KEYWORDS

Class A Biosolids, two-phase anaerobic digestion, primary solids, mesophilic, thermophilic

BACKGROUND

The Moccasin Bend Wastewater Treatment Plant (WWTP) serves the City of Chattanooga, Tennessee and ten surrounding regional customers in southeast Tennessee and north Georgia. Recent improvements have upgraded the liquids handling portion of the plant to 140 million gallons per day (mgd) of secondary treatment capacity with an additional 80 mgd of wet-weather treatment capacity. The second phase of the plant upgrade is to accomplish total system improvements to the solids handling portion of the plant and to give the plant the capability to produce Class A biosolids. Previous solids treatment consisted of anaerobic digestion of primary solids in six 65-foot anaerobic digesters, followed by blending with WAS and dewatering using plate and frame filter presses or centrifuges.

The solids digesters and system were installed with the original WWTP construction in the late 1950s, and continued operation until around 2001. In the 1980s and 1990s, the plant added
plate-and-frame filter presses and centrifuges for dewatering the solids. All of the dewatered biosolids was disposed in landfills. The operational and maintenance costs, including chemicals and disposal, continued to escalate. Many of the major equipment systems had exceeded their useful service life. The City decided that the WWTP’s entire solids handling systems needed upgrading.

The City and their engineers, a joint venture of ARCADIS G&M, Inc. and Consolidated Technologies, Inc., completed a preliminary engineering report to assess the plant’s solids handling needs for the future, and developed a series of eight alternatives. The preliminary engineering study and cost-effective analysis were conducted to evaluate alternatives to handle the increased solids loading and to achieve Class A biosolids. Separate treatment of the primary and WAS will allow more efficient thickening, processing and dewatering of the two different types of solids. With the selected alternative, WAS and primary solids are handled in two separate treatment trains. The study estimated that approximately 47 dry tons per day of primary solids will need to be handled by the year 2020.

Among the goals of the solids handling upgrades are:

- Minimize treatment and disposal costs
- Make marketable end product
- Minimize potential and perceived problems with disposal of biosolids
- Produce Class A Biosolids (40 CFR 503 – Federal Regulations)
- Utilize the existing facilities to the maximum extent possible.

The Moccasin Bend WWTP wanted the capability of producing Class A biosolids in order to produce a useable end-product and reduce disposal costs. Previously, the plant was disposing of all biosolids in a landfill. Class A biosolids will be achieved for the primary solids through the time-temperature requirement of the EPA’s 40 CFR Part 503 regulations (EPA 1993). This paper will discuss the improvements to accomplish Class A anaerobic digestion of the primary solids from the plant, the start-up process for digestion, and lessons learned during the project and start-up. The projects to complete improvements to handle the WAS are not covered herein.

**PROJECT DESCRIPTION**

Through a separate equipment procurement contract, the City and ARCADIS selected the anaerobic biosolids mixing, heating and digestion equipment. Infilco Degremont, Inc. was selected to provide digestion equipment, including the boilers for heating, Cannon® gas bubble mixing system, gas compressors, and new digester covers. The installation contract was designed around the selected equipment. The total cost of the equipment procurement contract is $3.1 million. The installation contract is $9.2 million. Installation began in 2003 and was completed in 2005.

The primary solids handling improvements were completed while maximizing use of the existing structural facilities, including two solids thickeners and six circular digesters. A 500,000 gallon solids storage tank, an addition to the primary solids pumping station, a gas scrubber building addition, and two small gas compressor buildings on the digester roof were the only new structural facilities constructed. The two 90-foot diameter thickeners were renovated with new
mechanisms. The six concrete digesters are 65 feet in diameter and were constructed as part of the initial WWTP construction project in the late 1950s. The digester structures were in relatively good condition. After demolition of the old equipment and piping, a protective coating was applied to the digester interior walls.

All of the old equipment and piping were demolished from the existing digesters and galleries. The new boilers, pumps, Cannon® mixers, and piping were installed within the existing digester structures. The nine new liquid-ring gas compressors were installed in buildings constructed on the roof of the digester building. Housing the digester gas compressors and piping on the roof allowed the remaining structure to avoid explosion-proof electrical requirements, resulting in substantial savings.

New covers were installed on the existing six digesters. Fixed covers are on the two thermophilic digesters and floating gasholder covers are on the four mesophilic digesters. The radial beam-type covers were delivered in sections and erected in place. Stainless steel gas piping was installed on the roof to handle the digester gas, which is used as mixing in the digesters and for fuel for the boilers. Excess digester gas can be flared off. The project included a new gas scrubber to remove hydrogen sulfide from the digester gas to enhance the gas as fuel for the boilers.

**PROCESS OVERVIEW**

Solids from the WWTP’s existing primary clarifiers are pumped to two 90-foot diameter thickeners. The existing mechanisms were replaced on the thickeners. The primary solids digestion process consists of temperature-phased anaerobic digestion at thermophilic followed by mesophilic temperatures. Digested biosolids are pumped to the new 0.5 MG biosolids storage tank, followed by dewatering in two new high-solids centrifuges purchased from Krauss Maffei Flottweg.

Solids are digested in one of two thermophilic digesters (Digester 1 or 2) at a temperature of 135º F to 140º F followed by mesophilic digestion at 95º F (Digesters 3, 4, 5 and 6). Each digester is 65 feet in diameter with sidewater depth of 25 feet. The digestion process is designed in a batch mode, generally via two “trains.” Train 1 consists of digesters 1, 3 and 5 while Train 2 utilizes digesters 2, 4 and 6. The installed piping, pumps and controls allow much flexibility to utilize all digesters for flexibility of operation. Figure 1 shows the digester process layout.
Incoming solids from the thickeners goes through a pre-heating heat recovery exchanger before injecting into the thermophilic digester. The biosolids are held at the target temperature for sufficient time to meet EPA’s Class A designation. It is currently planned that each digestion cycle will include a batch step of 6 hours at 59.3°C (138.7°F) to satisfy the time-temperature in accordance with the following equation in the Part 503 regulations:

\[
D = \frac{50,070,000}{10^{0.14t}}
\]

Where \( D \) = time in days
\( t \) = temperature in °C

Then, the thermophilic biosolids are pumped through another heat exchanger to reduce the temperature before entering one of two mesophilic digesters. Heat from the thermophilic biosolids is then transferred to the heat recovery exchanger for heating the cooler incoming solids. Figure 2 shows the process diagram and heating schematic.
The solids heating process is accomplished by hot water provided by one of two redundant boilers (8,340,000 BTU each). The boilers can be fueled by digester gas or natural gas as the backup. Six solids-to-water heat exchangers provide heat for the solids digestion systems. Biosolids from the two thermophilic digesters are re-circulated by three variable speed 1500-gallon per minute (gpm) progressive cavity pumps (two duty pumps plus one standby) through two heat exchangers to maintain the desired solids temperature. Automated controls monitor the digester temperature and adjust the variable speed pumps to maintain temperature.

A cooling system was installed with cooling tower, piping system and heat exchanger to provide capability to reduce the temperature of the thermophilic biosolids before transferring to mesophilic digesters and to reduce temperature in the mesophilic digesters during the hotter months.

Supervisory control and data acquisition (SCADA) system was installed to monitor the entire process, with automated control and alarms and capability to record the process (time, volume, temperature, etc.) for documentation of Class A digestion. The system allows the plant operators to monitor and control the anaerobic digestion system from the plant’s operations and control building without full-time attendance in the digester building.

**START-UP PROCESS**

Prior to starting up the first train of digesters, start-up guidelines with a recommended ramp-up schedule were developed to guide plant personnel through the start-up process. With no seed
solids available for process startup, the two trains of digesters were to be started up separately. Train 2 consisting of Digesters 2, 4, and 6 was started up initially. The goal is for Train 2 to provide seed solids for Train 1 once established. It was also decided to start up the train immediately in series as a two-phase digestion system, at the thermophilic and mesophilic temperatures, to accelerate the start-up process.

Digester 2 was filled with primary effluent wastewater to a point between the minimum and maximum operating levels. Digesters 4 and 6 were filled with plant water to above the minimum liquid level that seals the covers and allows the gas bubble mixers to operate. The air in the digesters and gas piping was purged with nitrogen gas to minimize combustion potential while the gas is converted from air to digester gas. The mixing was started in Digesters 2, 4 and 6 and Digester 2 was heated to a thermophilic temperature, 55°C (131°F). Digesters 4 and 6 were to be heated to a mesophilic temperature, 35°C (95°F).

Once 55°C (131°F) was reached in Digester 2, the feeding of primary solids was started on April 2, 2005. The feed primary solids were to be fresh with an age not exceeding 48 hours, 24 hours being recommended. The digesters were started up with two feeding cycles per day, initially direct from a primary clarifier. Later, as the plant dedicated Thickeners 1 and 2 for primary solids only, the plant switched to feeding from those thickeners. During the establishment of digestion in Digesters 2, 4 and 6; the important parameters for monitoring the digestion process were:

- Total suspended solids loading rate ($L_R$) in lb/ft$^3$/day
- Solids retention time (SRT) in days
- pH in Digesters 4 and 6

The anaerobic digestion was established in Digesters 2, 4 and 6 by progressively increasing the daily volume of feed solids, the solids retention time, and the TSS loading rate as indicated in Table 1. The TSS loading rate was based on an expected 4.0% TSS feed solids.

### Table 1 - TSS Loading Rate Ramp-up in Digesters 2, 4 and 6 for Two Daily Feedings

<table>
<thead>
<tr>
<th>Day</th>
<th>TSS Loading Rate (lb/ft$^3$/d)</th>
<th>Total Feed Volume (KGPD)</th>
<th>Total SRT (days)</th>
<th>Digestor 2 Feed Volume (Kgal)</th>
<th>Digestor 2 SRT (days)</th>
<th>Digestor 2 Feed Time (hours)</th>
<th>Digestor 4 Feed Volume (Kgal)</th>
<th>Digestor 4 SRT (days)</th>
<th>Digestor 4 Feed Time (hours)</th>
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<tr>
<td>0</td>
<td>0.019</td>
<td>13.03</td>
<td>133.3</td>
<td>6.52</td>
<td>44.4</td>
<td>0.62</td>
<td>3.26</td>
<td>88.9</td>
<td>0.31</td>
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<td>10</td>
<td>0.025</td>
<td>17.38</td>
<td>100.0</td>
<td>8.69</td>
<td>33.3</td>
<td>0.83</td>
<td>4.34</td>
<td>66.7</td>
<td>0.41</td>
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<td>18</td>
<td>0.031</td>
<td>21.72</td>
<td>80.0</td>
<td>10.86</td>
<td>26.7</td>
<td>1.03</td>
<td>5.43</td>
<td>53.3</td>
<td>0.52</td>
</tr>
<tr>
<td>26</td>
<td>0.044</td>
<td>30.41</td>
<td>57.1</td>
<td>15.20</td>
<td>19.0</td>
<td>1.45</td>
<td>7.60</td>
<td>38.1</td>
<td>0.72</td>
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<tr>
<td>32</td>
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<td>34.75</td>
<td>50.0</td>
<td>17.38</td>
<td>16.7</td>
<td>1.65</td>
<td>8.69</td>
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<tr>
<td>40</td>
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<td>46</td>
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<td>40.0</td>
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<td>13.3</td>
<td>2.07</td>
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<tr>
<td>52</td>
<td>0.075</td>
<td>52.13</td>
<td>33.3</td>
<td>26.06</td>
<td>11.1</td>
<td>2.48</td>
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<td>52.13</td>
<td>5.6</td>
<td>3.48</td>
<td>26.06</td>
<td>11.1</td>
<td>1.74</td>
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The digester feed times between day 0 and day 58 were calculated for a pumping flow rate of 175 gpm. It is recommended to use a moderate flow during the startup phase. After day 58, the pumping flow rate should be increased to 250 gpm.

Volumes of feed batches for Digester 2 were calculated for an average digester volume of 595,742 gallons. Volumes of feed batches for Digesters 4 and 6 are calculated for an average digester volume of 570,920 gallons based on average operating depths of 21.0 and 25.0 ft.

Figure 3 illustrates the data from Table 1 on total feed volume and total TSS loading rate.

After 72 days of a progressive increase in TSS loading rate, Digesters 2, 4, and 6 should have reached their design solids retention times of 5.5 days and 11 days, respectively. At this point, one digester train will have achieved normal operation as a two-phase digestion system.

**Figure 3 - Plot of Feed Volume and TSS Loading Rate Versus Time**

![Plot of Feed Volume and TSS Loading Rate Versus Time](image)

**STARTUP DATA AND EXPLANATION**

During the start-up, the process data was monitored daily for temperature, pH, and acid-to-alkalinity ratio. Two problems involving these parameters occurred shortly after start-up, which delayed the ramp-up schedule significantly. Digester 2 was quickly brought up to a thermophilic temperature, in the range of 59-60°C, but there were difficulties in getting Digesters 4 and 6 up to the mesophilic temperature (35°C). Problems with the hot water control valves prevented these digesters from reaching mesophilic temperatures during April and almost half of May. The valves were repaired which enhanced ability to provide heat to the mesophilic digesters. Also,
once heated thermophilic biosolids were transferred into the mesophilic digesters, the solids temperature increased. The operating temperatures in Digesters 4 and 6 were brought to about 35-37°C. The fluctuations in weather and temperatures present a challenge for controlling the digester temperatures. Control of temperatures in thermophilic and mesophilic digester has improved as the operators gained experience in the system.

Second, the pH in Digesters 4 and 6 dropped too low, in the range of about 5.8-6.4 as compared to a minimum objective of 6.8 for mesophilic digesters. We had not been successful in establishing the methanogens in Digesters 4 and 6, which produce alkalinity. It seemed that the methanogens were inactivated upstream in Digester 2, therefore preventing any chance of them growing in Digesters 4 and 6. Another option would have been to seed Digesters 4 and 6 with primary solids, which contains natural strains of methanogens.

After start-up, the solids loading had to be reduced below the ramp-up schedule and finally solids transfer to Digesters 4 and 6 had to be stopped to prevent the mesophilic digesters from further souring due to the low pH. The reduction began April 11 and the reduction/stoppage lasted until about mid-July.

Caustic (sodium hydroxide) mixed with a minimal volume of primary effluent were fed to Digesters 4 and 6 to try to raise the pH to a minimum of 6.8. Lime was not used due to concern with lime solid accumulation in the system. The amount of caustic to be added (pounds per 1000 gal) was determined by performing a laboratory titrimetric measurement on a solids sample. Tests showed that approximately 250 gallons in each digester would be adequate. The method of feeding caustic into Digesters 4 and 6 was by filling the primary solids pump station with primary effluent wastewater and adding caustic to the wet well.

Following the initial pH problem, we erred on the side of caution and kept the feed rate to a low level for possibly longer than was necessary. Once we got back on the schedule, the ramp-up progressed smoothly (see Figure 4 for the actual ramp-up curve and the average pH in the mesophilic digesters).
When the loading reached 84,000 GPD on September 20, the plant went to three feedings per day because of the drawdown limit for Digester 2. The operating range on digesters 1 and 2 is approximately 1.67 feet. Minimum solids level must be maintained above the cover side skirts and above the mixers. Otherwise, the cover seal would be broken.

Full loading was reached October 10, 2005. There was a jump in the volatile acids in Digester 2, at the end of October, from about 200 to 1800 mg/l. It stabilized around 1200-1800, with a volatile acids-to-alkalinity ratio of about 0.80-1.20. It was expected that Digester 2 would eventually revert to an acidogenic digester. The volatile acids-to-alkalinity ratios in Digesters 4 and 6 have stabilized at about 0.02-0.03, which is excellent. Digesters 4 and 6 have enough of an alkalinity buffer now and can take this acidity increase without significant concern.

The feed TSS initially was about 3% to 4% or greater, as expected, but this was during the period when the feed solids came from a primary clarifier. This clarifier was dedicated to the start-up and the detention time was greater than normal to get thicker solids. When the switchover was made to the solids thickeners, the concentration dropped to about 2% to 2.5% and later dropped to about 1.8%. It has gradually increased to about 2.4%. Figure 4 also indicates the actual TSS loading rate in pounds per cubic foot per day during the ramp-up.

At the time this paper was written, startup and feeding of the second train had not yet been initiated. It is envisioned that digesters 1, 3 and 5 will be filled with plant effluent and then the digesters be heated to design temperatures. Thickened primary solids will be fed into Digester 1 at designated intervals and volumes. Seeding Digester 1 with digested thermophilic biosolids is not required as acid forming bacteria are also present in the primary solids. Since Train 2 is operating at near capacity, it is important to continue to feed, digest and withdraw to maintain the
digestion processes in Train 2. Digested biosolids from mesophilic Digesters 2 and 4 will be fed into Digesters 3 and 5 during startup of Train 1 with the goal decreasing overall time to reach capacity.

LESSONS LEARNED

1. Provide means to add acid, caustic or other chemical additives to adjust digester, especially during startup (e.g. piping connections to inject chemicals into incoming solids line).

2. Expect several months of “real world” process startup time. Chances are good that something will change or occur that will extend startup time. The projected start-up time for Train 2 was 72 days, but it turned out to be over 6 months. In addition to the temperature and pH problems discussed here, there were mechanical problems that added to the delays.

3. For startup of Train 2, Digesters 4 and 6 were initially filled with just plant effluent. It is possible that the digesters could have been seeded with primary solids, which contains natural strains of methanogens. We may have gotten to the objective pH of 6.8 much more quickly and probably avoided having to feed caustic for pH adjustment.

4. For the startup of Train 1, Digesters 3 and 5 (mesophilic digesters) will be fed with digested mesophilic biosolids to reduce the theoretical ramp-up time. Digested biosolids were not available for the initial start-up.

5. Thickened primary solids to the digesters were expected to be around 4%. Actual solids feed was around 2% to date. This has limited the solids loading rate to the digestion system to less than designed even while the hydraulic loading rate is at capacity.

6. From an Operations standpoint, the advantages of starting one train at a time included: any problems with “sour” digesters would only affect three full tanks instead of six; and establishing one train slowly would provide seed solids for the second Train to be started up more quickly. However, we discovered that the disadvantages were: all feeding and transfers and associated valve changes, etc. had to be done manually, since the second train was not alternating with the first Train; and preheating of incoming primary solids to the thermophilic digester was not available, again due to not having the alternating Train in operation (this caused challenges with maintaining thermophilic temperatures after feeding).

7. Maintaining thermophilic and mesophilic temperatures in all the digesters by this system has been a real challenge for the plant operators. The temperature sensors inside the tank contents did not indicate to operators the solids temperatures entering or exiting the tanks via the heat exchangers. City personnel requested four additional temperature sensors for this purpose. Additionally, except for the relationship of the thermophilic digester contents temperature with the speed of the recirculating pump, there is no direct relationship of digester temperatures to the water heating/cooling system. This has caused many operational challenges, particularly at seasonal changes, where operators must make best judgments as to water temperature settings needed for the desired digester content changes.
REFERENCES