ABSTRACT

The Western Lake Superior Sanitary District (WLSSD) is located on the western shore of Lake Superior in Duluth, Minnesota. Five years ago, the WLSSD undertook a major change in its biosolids program, shifting from sludge co-incineration with solid waste to temperature phased anaerobic digestion (TPAD) and land application. The WLSSD wastewater treatment plant treats average flows of 162 million liters/day (43 million gallons/day). A majority of the loading to the plant’s liquid stream treatment system, oxygen activated sludge, comes from paper mill wastewater making the waste activated sludge higher in poorly-degradable volatile solids than conventional municipal sludge for anaerobic digestion. In addition, all influent flow goes directly to the oxygen activated sludge system without primary treatment, contributing to the lower-than-typical digest-ability of the sludge. Pilot studies conducted on the sludge prior to commencing design indicated that the TPAD process could achieve significantly higher volatile solids destruction than conventional mesophilic digestion and produce a well-stabilized product suitable for land application.

Following initial positive results from pilot work, the TPAD system was recommended and the new facility was designed, built, and went on line in May 2001. TPAD incorporates thermophilic and mesophilic digesters operated in series. The TPAD process biogas is captured and used for plant and digester heating. Biosolids are dewatered by new centrifuges, achieving an average of 27 percent solids prior to land application.

The TPAD process at WLSSD utilizes a single, one-million-gallon (MG) thermophilic digester that receives all raw waste activated sludge, thickened to 5.0 to 6.5 percent, followed by three, one-million-gallon, mesophilic digesters operating in parallel. The nominal design hydraulic residence times are 5 days for the thermophilic digester and 15 days for the mesophilic digesters. The thermophilic digester is heated by the plant heating system, supplied by dual-fuel, low-pressure, steam boilers. All digester gas is used in the boiler system for plant and process heating. A heat recovery system is used to cool the thermophilic sludge prior to being fed to the mesophilic digesters. Recovered heat is used for building heating except during the warm summer months when it is routed to a cooling tower.
This paper presents the background and basic design elements of the system and focuses on the first 5 years of the TPAD system operation. The paper focuses on system organic and hydraulic loading rates (OLR and HRT), volatile solids destruction (VSR), volatile acid production (VA), ammonia concentrations, system stability, pathogen destruction, gas production and quality, and other basic digestion performance parameters. Performance variation with variable liquid stream treatment solids retention time (SRT) and temperature are discussed. Performance and information on mechanical systems are also discussed.

KEYWORDS

Anaerobic digestion, temperature phased digestion, thermophilic digestion, Class A biosolids, enhanced digestion

PROJECT BACKGROUND

The Western Lake Superior Sanitary District (WLSSD) is responsible for collection and treatment of wastewater and solid waste management for a 500 square-mile area encompassing the City of Duluth, Minnesota and surrounding communities. The WLSSD wastewater treatment plant treats average flows of 162 million liters/day (43 million gallons/day), with approximately two thirds of its load coming from local pulp and paper industries. The plant was built in the mid-1970s and consists of liquid processing steps as follows: influent bar screens, grit removal, pure oxygen activated sludge reactors, clarification, effluent filtration, chlorination, and dechlorination. The plant has no primary sedimentation. In the mid 1990s, the WLSSD planned to phase out the incineration process for both solid waste and biosolids and selected anaerobic digestion as the preferred biosolids treatment option prior to beneficial use. The project consisted of four, one-million-gallon digesters to operate in the temperature phased mode; new centrifuge facilities to replace aging belt filters; upgrades to the existing dissolved air flotation thickeners, liquid sludge storage tanks, and odor control system; conversion of the solid waste receiving station to a dewatered-biosolids storage facility; and the construction of a new, remote, dewatered-biosolids storage facility.

The WLSSD believed their digested biosolids would have good market and low nuisance potential, but were interested in the possible improvements with enhanced digestion technologies, specifically temperature phased digestion, and with the potential for achieving Class A biosolids to enhance marketability. In the fall of 1997, the WLSSD contracted with Iowa State University (ISU) at Ames, Iowa to conduct pilot testing because of ISU’s extensive experience and research in temperature phased anaerobic digestion (TPAD). The one year of testing was to evaluate the compatibility of the TPAD process compared to conventional mesophilic digestion with WLSSD sludge, help define design parameters for a full scale TPAD process, and assess digestion performance and Class A potential compared to pre-pasteurization followed by mesophilic digestion. The pilot tests, more fully documented elsewhere (Schafer, et al, 2000 and Chao et al, 1999), concluded that the TPAD process, treating the high pulp content WLSSD sludge, could achieve volatile solids reductions of 42 to 47 percent with system hydraulic retention times (HRT) of 20 days while conventional mesophilic digestion required 30 days HRT to achieve 40 to 41 percent VSR. The pilot tests also confirmed stable operation of the TPAD system with shock loadings down to 10 days HRT (2.5 days thermophilic and 7.5 days...
mesophilic), providing useful data for determining design peak load conditions for the new TPAD system. Recognizing that volatile solids reductions were close to the 38 percent required by EPA for vector attraction reduction (VAR), additional digestion tests were conducted according to EPA protocol. Additional VSR is required to be less than 17 percent after 40 days following this protocol. Product sludge from the 20-day system HRT test configuration resulted in additional VSR of 3 percent after 40 days of additional digestion. Sludge from low system HRTs of 10 and 12 days, resulted in additional VSR of 13 percent. It was recognized that although the TPAD system, treating the high-pulp-fraction WLSSD sludge, would provide a well stabilized sludge meeting requirements for limiting vector attraction, the full scale process may require the WLSSD to occasionally perform the additional digestion test for verification. Finally, whereas the TPAD product was found to have fecal coliform below the 1000 MPN Class A limit, no definitive conclusions could be drawn with respect to the long term performance of the TPAD configuration and its ability to achieve a consistent Class A product.

SYSTEM DESIGN

The new biosolids treatment system begins with dissolved air flotation thickening of the waste oxygen activated sludge to a concentration of between 5.0 and 6.5 percent total solids. Thickened solids are pumped from two thickened-sludge blending wells to the new TPAD digesters. Four TPAD digesters, each with 1 million gallon capacity, are arranged with the first digester (Digester 1) to be operated in the thermophilic range (55 degrees C) followed by three mesophilic digesters (36 degrees C) to be operated in parallel (Digesters 2 through 4). A TPAD system process schematic is shown in Figure 1.

Digester 2 has the capability to operate in the thermophilic range either as a standby or in parallel with Digester 1. Thickened sludge is pumped first into Digester 1 for thermophilic treatment and from there pumped to Digesters 2 through 4 for mesophilic polishing. Final digested sludge is pumped to two sludge storage tanks prior to dewatering. Two high solids centrifuges have been installed for dewatering followed by conveyors to an adjacent cake storage building prior to hauling to local agricultural lands.

Careful consideration was given to digestion reactor sizing and resultant loads from peak solids production from the plant. Several configurations and sizes were analyzed, and ultimately, with assurances on shock load capability from the ISU pilot tests, the design size was selected. Table 1 shows the TPAD reactor HRTs at average and maximum loads, with 4 and 3 reactors in service, and feed total solids of 5 and 6 percent. Whereas the system can be considered to have a nominal 5/15 HRT design (thermophilic HRT/ mesophilic HRT) based on average loads at 5 percent feed solids, it will handle peak week HRTs of 3.6/10.8 and peak daily HRTs as low as 3 days in the thermophilic reactor.
The digesters are 75 feet in diameter, each with four mechanical draft tube mixers. They are designed with submerged, fixed-covers, allowing the operating sludge surface to remain constant at the normal overflow level within the 16-foot diameter gas dome at the top-center of the cover. The thermophilic reactor is heated using spiral heat exchangers in a digester recirculation loop with heat provided by a plant-wide hot water system. Digesters 2 through 4 are designed to be cooled similarly using cooling heat exchangers in sludge recirculation loops. Cooling water for
Sludge cooling can be circulated through heating coils to provide building heat during nine months of the year. During the warm summer months, excess heat can be dumped to atmosphere using cooling towers. Digester gas is burned in dual-fuel, low-pressure, steam boilers to supply building and process heat. It is also used to fuel two, 70 kW micro-turbines. Some excess gas is flared to atmosphere. Principal system design data are presented in Table 2.

### Table 2 - Key Digester System Design Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value or Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Digester Feed</strong></td>
<td></td>
</tr>
<tr>
<td>Average Annual</td>
<td>41 dry tons per day</td>
</tr>
<tr>
<td>Maximum Month</td>
<td>48 dry tons per day</td>
</tr>
<tr>
<td>Total Solids</td>
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</tr>
<tr>
<td>Volatile Solids</td>
<td>75 to 80 percent of TS</td>
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<tr>
<td><strong>Digester</strong></td>
<td></td>
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<tr>
<td>Number</td>
<td>4</td>
</tr>
<tr>
<td>Volume, each</td>
<td>1.05 million gallons</td>
</tr>
<tr>
<td>Diameter, feet</td>
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<tr>
<td>Side water depth (SWD), feet</td>
<td>32</td>
</tr>
<tr>
<td>Cover type</td>
<td>Fixed Submerged Concrete</td>
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<tr>
<td>Mixers, number per digester and type</td>
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<tr>
<td><strong>Exchangers</strong></td>
<td></td>
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<tr>
<td>Heating Exchangers, Digesters 1 and 2</td>
<td>Spiral</td>
</tr>
<tr>
<td>Cooling Exchangers, Digesters 2, 3, and 4</td>
<td>Spiral</td>
</tr>
<tr>
<td><strong>Digester Gas Production</strong></td>
<td></td>
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<tr>
<td>Average Annual</td>
<td>19,000 ft³ per hour</td>
</tr>
<tr>
<td>Maximum Day</td>
<td>38,000 ft³ per hour</td>
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<tr>
<td><strong>Digester Gas Boiler</strong></td>
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<tr>
<td>Number, type</td>
<td>Low pressure steam</td>
</tr>
<tr>
<td>Capacity</td>
<td>300 hp</td>
</tr>
</tbody>
</table>
OPERATIONAL RESULTS

The WLSSD TPAD system has performed well since startup. Over the last five years, total solids feed concentration has ranged from 5.1 to 6.3 percent with an average of 5.7 percent. Digested sludge total solids concentration has ranged from 1.9 to 4.2 percent with an average of 3.7 percent. The system has operated at an average total solids load of 34 tons per day and an average system HRT of 27 days. This is somewhat below the system design loading of 41 tons per day and above the design HRT of 25.5 days (at 6 percent feed). Volatile solids concentration into the digesters has averaged 80.5 percent. Volatile solids reduction has averaged 45 percent.

Figure 2 shows the thermophilic and mesophilic reactor temperatures over this period. Thermophilic temperatures have remained very stable at or slightly above 130 degrees Fahrenheit (F) except for one excursion in late 2002. Operations staff has experimented with several different operating modes for the mesophilic reactors. Whereas they started operations in 2001 at the traditional mesophilic 98 degrees F, cooling was stopped and their temperature was allowed to float between 115 and 125 degrees in 2003. In June of 2004, staff elected to bring the cooling system back on line and since then have maintained temperatures of about 106 degrees in the mesophilic reactors. Discussions below will point out where these different operating temperatures appear to have impacted performance or other operating parameters.

Figure 2 – Digester Operating Temperatures
Figure 3 indicates that the system has performed well since startup. Volatile solids reductions have remained stable, consistently in the 40 to 50 percent range. One short term excursion below 38 percent VSR (required for vector attraction reduction) appear to be related to a short period of operational adjustments to digester operating temperatures. Thermophilic temperatures dropped from 131 degrees F to about 125 degrees F coincident with a sudden increase in mesophilic temperature from 98 to 118 degrees F. The lowered VSR appears to be a response to both lower than optimum thermophilic temperatures and the sudden rise in mesophilic temperatures. Sustained operation of mesophilic reactors at the higher temperature did not appear to negatively impact VSR performance. However, operations staff reported that the VSRs were more erratic prior to June of 2004 during the period of floating mesophilic temperatures. The VSRs have been more stable and better able to handle shock loads since that time when mesophilic temperatures have been held at 106 degrees F. Under conditions of VSR below 38 percent, tests have shown additional VSR, tested by EPA protocol, well below required levels. The VSR is calculated using a running average mass balance approach over approximately two system detention times (60 days for the TPAD system).

Fluctuating pulp mill waste contributions to the plant also affect the consistency of VSR performance. Operations staff have observed that VSR can drop during a “coatings” spill or discharge from a pulp mill. During these events, the volatile solids (VS) into the digesters, which normally average about 79 percent, can drop to as low as 65 percent due to high-fixed solids input. Conversely, a spill or discharge of “soap”, a byproduct of a Kraft pulp mill, increases VSRs. Described as having the consistency of thick molasses, it has a biochemical oxygen demand of about 650,000 ppm, high volatile acids, and produces an easily-digestible biomass. The increase in VSR to 50 percent in 2005 was attributed by operations to be the result of “soap” discharges from a pulp mill.
Figure 4 indicates that the VSR has remained consistent over system HRTs between 22 and 32 days. System design average HRTs are 21.2 to 25.5 days at 5 and 6 percent feed solids, respectively. Figure 5 indicates that lower HRT in the thermophilic reactor slightly reduces VSR in that reactor. Thermophilic digester VSR typically ranges between 30 and 40 percent and at an average of about 33 percent. However, the second stage reactors reduce the added VS load and the overall system VSR stays consistent.

**Figure 4 -- TPAD System VSR versus System HRT**

**Figure 5 – Thermophilic Stage VSR versus HRT**
Figure 6 presents VS reduction across the thermophilic reactor and the system as a whole versus organic loading rate on the thermophilic reactor. The data indicates that both the thermophilic reactor and the system as a whole can process high and variable organic loads with consistent VSRs.

As shown, the VSR actually increases slightly as the loading rates increase in the range of 0.40 to 0.48 lb VS/cu ft. This was unexpected and could be attributable, as discussed above, to discharge of “soap” from a Kraft pulp mill, which produces a highly digestible biomass during treatment. It also could be partially attributable to short-term higher organic loads coming principally from the municipal fraction of plant influent load, reducing the influence of the less-degradable pulp waste fraction of the load.

These results indicate the robustness of the thermophilic biomass in particular and the system biomass as a whole at these high rates. It should be noted that due to the high pulp fraction in the WLSSD sludge, a lower fraction of the volatile solids is digestible than with a more typical municipal sludge. Therefore, this loading rate must be compared to other municipal applications with caution.

Over the past five years, operators have adjusted liquid stream SRTs to control filaments affecting secondary effluent. Incidental observations were made during these events that VSRs trended down at high liquid stream SRTs. These observations have led to the hypothesis that longer liquid stream SRTs will reduce availability of digestible fractions, resulting in lower VSR across the digesters.
Figure 7 shows a plot of digestion system VSR versus the liquid stream SRT. The data does not support this theory. Digestion VSR is either independent of liquid stream SRT or other operational changes coincident with liquid stream SRT increases are counteracting the influence on VSR results. One concern with this comparison was that the daily reported SRT may not be representative of the load on the digesters with much longer HRTs. An inspection of the data indicated that long periods of low or high liquid stream SRTs did not influence digester VSR.

**Figure 7 -- Digestion VSR versus Liquid Stream SRT**

Figures 8 and 9 present volatile acid data and volatile acid-to-alkalinity (VA/Alk) ratios over time in each of the reactors. Over the last two years, volatile acids in the mesophilic reactors have stabilized in the 800 to 1000 mg/L range.

With the thermophilic reactor loading averaging about 0.45 lb VS/cu ft, the VA/Alk ratio has remained stable between about 0.15 and 0.20. The organic load on the mesophilic reactors has averaged about 0.09 lb VS/cu ft with a VA/Alk ranging from 0.10 to 0.15. The organic load on the thermophilic digester has been double what would normally be considered appropriate for a conventional mesophilic digester while maintaining stability and excellent performance.
As further evidence of process stability, Figures 8 and 9 indicate that VAs and the acid-to-alkalinity ratio for the system are within the expected ranges and have been dropping over time. Drops in these parameters over time are attributable to continued process operational improvements including measures to maintain a consistent, stable second stage temperature starting in early 2004.

**Figure 8 -- Volatile Acids Concentration versus Time**

![Figure 8](image1)

**Figure 9 -- Acid-to-Alkalinity Ratio versus Time**

![Figure 9](image2)
Figure 10 indicates that the ammonia concentration in the digesters has remained between 1500 and 2000 mg/L in the thermophilic reactor and between 2000 and 2500 mg/L in the mesophilic reactors through the operational period. As expected, ammonia concentrations have risen from thermophilic to mesophilic proportional to the increase in system VSR. This has also increased alkalinity. The excellent performance shown in Figure 3 is indicative of system acclimation to these ammonia levels.

**Figure 10 -- Ammonia Concentration versus Time**

During design, concern was expressed about potential for ammonia toxicity with the high design OLR. Total ammonia levels above 1500 mg/L were considered potentially inhibitory in the elevated pH ranges anticipated. Digester bacteria can acclimate to higher ammonia concentrations, however, performance reliability can suffer. The WLSSD had consistently generated 6 percent total solids and above out of their dissolved air flotation thickeners and this high feed solids concentration had previously been associated with generating high enough ammonia concentrations to be of concern. Lowering the feed solids and ultimately the solids concentration in the digester was considered the principal avenue for controlling this if toxicity were indicated. During the course of the ISU pilot testing discussed above, this issue was explored by running side-by-side tests on TPAD systems using the WLSSD sludge at common hydraulic retention times and with feed solids of 5 and 6 percent. The ammonia concentrations ranged from 1200 to 1600 mg/L for the 5 percent TS feed and from 1500 to 2400 for the 6 percent TS feed tests. No significant difference in VSR was seen between the two systems, leading to the conclusion that ammonia toxicity was not evident. However, sufficient concern was expressed to lead to the decision to design for HRTs assuming 5 percent feed. Higher feed solids would be tried in full operation and if evidence of inhibited performance were seen, the feed solids concentration would be lowered. Feed solids concentrations have averaged 5.7 percent over the last five years and ammonia levels have stabilized in the 2000 to 2500 mg/L range (mesophilic reactors). The data does not indicate a clear relationship between ammonia concentrations and feed solids concentrations in the range of 5.1 to 6.3 percent. Overall system
performance has been consistent with that projected during pilot testing and no clear indication of ammonia inhibition has been seen.

Figure 11 presents limited Fecal Coliform data available for the year 2005. As has been seen in other complete mix thermophilic reactors, typical Fecal Coliform counts are well below 200 MPN per gram. However, an occasional “bleed through” event can cause an excursion above 1000 MPN per gram. This is the basis for EPA’s requirement for batch processing at elevated temperatures to assure Fecal Coliforms remain below 1000 for Class A approved systems.

**Figure 11 – Fecal Coliform Data**

![Figure 11 - Fecal Coliform Data](image)

Figure 12 presents digester gas data. Carbon dioxide concentrations ranging from 31 to 35 percent are indicative of well functioning methanogens. The H$_2$S concentration in the digester gas was considered during design to be a potential odor source. Therefore, ferric chloride addition facilities were added to reduce H$_2$S concentrations if they became problematic. The ferric addition is also used to tie up phosphorous and reduce its concentration in the plant effluent coming from dewatering centrate. As seen in Figure 12, through July and August 2001, levels ranged from 1500 to 2300 ppm. In late July of that year, the plant staff began addition of ferric chloride to test its performance. The H$_2$S concentration dropped almost immediately. After tests at various dosages, a dosage of about 400 lbs per day Fe$^{3+}$ was maintained resulting in H$_2$S below 1000 ppm. Operations staff has reported that the sulfur content of the lime used at the pulp mill for bleaching varies widely and has a dramatic impact on H$_2$S in the digester gas. Current H$_2$S concentrations are typically below 50 ppm with a ferric chloride dose of around 30 lbs per dry ton of solids (approximately 1000 lbs per day).

Figure 13 presents specific digester gas production. Problems with gas flow measurement before 2004 have made data reported prior to that time unreliable. Improvements to the gas system
flow measurement since have resolved the issue. Stable specific gas production of between 16 and 20 cubic feet per pound of VS destroyed has been indicated since.

Figure 12 -- Thermophilic Digester Gas CO\textsubscript{2} and H\textsubscript{2}S

![Figure 12](image)

Figure 13 -- Specific Digester Gas Production

![Figure 13](image)
OTHER OPERATIONAL CONSIDERATIONS

In addition to the performance of the digesters, the dewaterability and physical characteristics of the product sludge is of interest. The new high-solids centrifuges have consistently produced a cake between 27 and 31 percent solids with an average of 29 percent solids at a polymer dose of 33 lbs/dry ton. The product has an ammonia odor, which dissipates quickly and has not translated to noticeable odor outside of the storage building or to the field. As reported by Murthy et.al., experiments by operations staff have led to the conclusion that there is a noticeable improvement in initial odor of the product after a reduction in centrifuge torque due to a reduction in protein shearing. Operations staff has continued to operate at lower torque despite a few percentage points drop in cake solids to an average of about 25 percent. Product acceptance by local farmers is very high.

Mechanical issues of note have included complexity and control of the sludge cooling system, ragging of the circulation grinder pumps, struvite buildup that depresses performance in the heat exchangers and boilers, and level measurement in the digesters.

In colder months, the heat recovery system is used to control to mesophilic temperatures and recover heat for building use. The cooling tower is used from May through October. Early in the facility operation, oscillations in the mesophilic feed sludge temperature due to cooling tower operation were found to be problematic. The packaged cooling tower system has several layers of control depending on external environmental conditions. Damper controls, several fan speeds, and spray water requiring pretreatment all combined for control complexity when trying to maintain 98 degrees F in the mesophilic sludge during hot, humid summer weather. The cooling system was found to reliably control to 106 degrees F during these conditions and, as can be seen in Figure 2, has been stable at that temperature since mid-2004. Plant operations staff currently makes adjustments to the cooling tower controls manually. A supplemental cooling system using City water performs reliably to maintain 98 degrees F, but has been locked out due to high cost of the water.

In 2002, an independent process consultant recommended turning off the cooling system and allowing the mesophilic temperature to “float”. As shown in Figure 2, mesophilic temperatures varied in the 110 to 125 degree range. Although no overall drop in performance was evident, plant staff did note lower system stability in terms of consistent VSR as the temperature fluctuated. They elected to reduce the temperature to the stable 106 degrees in 2004 in part to reduce product odor. Comparison of temperatures and VSR across those reactors has shown no impact on performance at the higher mesophilic temperature (106 degrees F). As discussed above, one event of low VSR in early 2002 is attributable in large part to a rapid increase in mesophilic temperature coincident with a drop in thermophilic temperature. Data indicates that stability of temperature is more important to performance than the absolute temperature. Rapid changes in reactor temperature should be avoided except during initial startup when rapid increase to desired operating temperatures has proven more effective than slow gradual increases.

Early in the facility operation, thickened waste activated sludge was being fed to the digester at 6.5 to 7 percent solids concentration, above the system’s maximum design concentration of 6.5
percent. Solids concentration in the digesters increased to about 5 percent. Under these conditions the intake to the centrifugal chopper pumps used for digester recirculation became bound and digester heating was impaired. Feed solids were subsequently reduced to within design operating range and the issue was resolved. Feed solids and digested sludge concentrations over the last five years have averaged 5.7 percent and 3.7 percent, respectively, and the pump binding problem has not recurred.

Operations staff has attributed the drop in thermophilic temperature in 2002 to the loss of heat due to a plugged heat exchanger. In investigating the cause, they discovered severe wear on the recirculation chopper pump feeding the heat exchanger and loss of pumping capacity. Pearlite, a volcanic silica discharged to the plant from a local pulp mill, was suspected as the cause. The pearlite is extremely abrasive, has a density of about 4 lb/cubic foot and floats in the liquid process stream. It re-enters the process stream through the dewatering centrate and is therefore difficult to get out of the plant. Plant staff has undertaken manual cleaning of floatables consisting of plastics and pearlite “snowballs” from the centrate storage tank, which has significantly reduced the recirculation pump wear. The heat exchangers have not completely plugged since undertaking these measures and rebuilding the recirculation pumps, however debris accumulation in the heat exchangers remains a maintenance issue.

Early in the design process, a Strainpress (by Parkson Corporation) was included in the design to remove debris from the feed sludge. The Strainpress was removed as part of measures to reduce project construction cost. It was decided that strategically located grinders in the system along with chopper-type pumps for recirculation would adequately prevent clogging problems and that the Strainpress could be added in the future if desired. The plant headworks has 3/4-inch screens and unscreened plastics often pass untouched through grinders and chopper pumps. As routine maintenance, plant staff currently open the heat exchangers every 3 or 4 months to clean out any accumulated rags and plastic debris. The heat exchangers are also pressure washed at this time to remove struvite buildup of approximately 1/32 inch.

As discussed above, ferric chloride is added to the digesters to control hydrogen sulfide. Despite relatively high doses which would be expected to remove most phosphorous, struvite has been seen to build up in the heat exchangers and boilers requiring occasional cleaning.

Level measurement for the digesters was designed using pressure transducer level instruments. Variation in specific gravity of the sludge can result in inconsistent level readings and have caused occasional overflows to the provided high-level overflow system for digester number 1. Specific gravity can vary with sludge consistency, during periods of high gas production, and when reversing sludge mechanical mixers, causing a change in the velocity gradient of rising gas bubbles. It was determined that the overflow events were caused principally during reversal of mechanical mixers and the issue was resolved with gradual ramp-up of mixer speed after flow reversal. An overflow of the digested sludge storage tank was also attributed to the inaccuracy of the pressure transducer level instruments. Plant operations staff corrected the issue by adding an ultrasonic level measurement to the top of the storage tank and adding a float switch for high-level lockout of the feed pumps.
Overall, operations staff has reported the TPAD system and in particular the thermophilic digester to be very robust, requiring very little operator attention to maintain stable operation. No foam has ever been experienced in the digesters, despite several foaming events in the liquid stream. To date the digesters have not been taken out of service for cleaning.

CONCLUSIONS

Once appropriate microbial concentrations are established, the TPAD process can perform reliably and up to expectations. Care needs to be given to specific mechanical issues to optimize system operability.

ACKNOWLEDGEMENTS

We wish to thank the management and staff of the Western Lake Superior Sanitary District. We would like to express particular thanks to the operations, maintenance and laboratory staff at the WLSSD for their contributions to the design and committed efforts during startup and operation of the new system.

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