Miami-Dade Water and Sewer Sludge Thickening and Dewatering Centrifuge Pilot Studies at Two of the Southeast's Largest Wastewater Treatment Plants

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Miami-Dade County embarked on a biosolids planning effort in 2006 and produced a final biosolids master plan in 2008. The goal of the plan was to determine a path forward for Miami-Dade Water and Sewer Dept. (MDWASD) to process biosolids in an efficient and effective manner that would meet future growth and upcoming regulatory requirements in the state of Florida.

Several capital programs and a decade later, MDWASD is in the mist of constructing, design, and planning aspects of that biosolids master plan that so fundamentally showed that, through better technology, new philosophies in biosolids treatment, better appreciation for the environment, and purpose of the end product, there was a more sustainable way.

One of the early key observations of that biosolids master planning effort was that sludge gravity thickening in the constantly hot and humid conditions of south Florida is very prone to septic conditions. These conditions manifest in poor sludge thickening (lower thickened sludge concentrations), a high solids rejection rate (poor solids capture), and frequent process upsets, resulting in the bulking of the sludge blanket. In essence, gravity thickeners are primarily designed for primary, lime, and combined sludges, but poorly suited for waste activated sludge (WAS), producing lower sludge underflow concentration and lower solids recovery (WEF MOP No. 8, fifth edition, 2008).

Miami-Dade County's experience with normal operation of sludge gravity concentrators has been a constant battle to fight process failure, rather than an opportunity of optimizing a process for better performance. The solution and design consideration proposed was the basis of a multiplant design-build project with mechanical thickening of sludge to 5 to 6 percent total solids (TS) from the current 2 to 4 percent TS thickened sludge concentrations.

As a part of the MDWASD consent decree with the U.S. Environmental Protection Agency (EPA), the utility agreed to rehabilitate its existing gravity thickening process at its South District Wastewater Treatment Plant (SDWWTP) and Central District Wastewater Treatment Plant (CDWWTP). In the progression of initial planning efforts at the behest of the utility's operations staff, process engineers, and local regulators, the plan changed from rehabilitation of the existing thickening process to something proven to work in hot and humid climates, be easier to properly operate and maintain, and produce much higher thickened sludge concentrations in a stable process.

The debate concerning rotary drum thickeners, gravity belt thickeners. and thickening centrifuges went on throughout the basis of the design period. Due to their high throughput, space considerations, and the utility's familiarity with dewatering centrifuges to allow for similar operations and maintenance, centrifuges were selected as the technology to design around for thickening (WEF MOP No. 11, sixth edition, 2008). This in turn deemed that careful study of centrifuges was merited based on concerns over the specific sludge conditions and downstream process impacts at both plants.

In tandem with changes to sludge thickening, the anaerobic digestion process at each plant is being modified from two-stage mesophilic anaerobic digestion (with heated and mixed primary digesters and unheated, minimally mixed secondary digesters) to single-stage mesophilic anaerobic digestion at CDWWTP and acid-gas mesophilic anaerobic digestion at SDWWTP, with all rehabilitated digesters having the capacity for heating and mixing. As the thickened sludge concentration would be higher, the study incorporated mesophilic anaerobic digestion at steady state under these high-feed solids condition at a 20-day detention time, as these would be the proposed future design condition.

Due to the equipment age and the vast improvements in energy efficiency of newer, lighter machines, the dewatering centrifuges were slated for replacement as part of the consent decree. The ripple effect of the aforementioned process changes impact-digested sludge concentrations, and potentially, sludge dewaterability. The pilot study included the testing of the future dewatering feed sludge conditions on both the dewatering centrifuge design considerations and final dewatered sludge quality and quantity to achieve a 24 percent cake solids concentration, with 95 percent solids capture rate.

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Facility Background

The SDWWTP is located in the southeastern portion of Miami-Dade County and serves its southern and southwestern portions. The plant is a high-purity-activated sludge secondary treatment facility, with a permitted capacity of 112.5 mil gal per day (mgd).

The SDWWTP produces only WAS, and wasting is controlled using a modulating valve and flow meter that is tapped off at the return activated sludge pumps. The WAS is mixed with polymer in the piping and sent to four 55-ft-diameter gravity thickeners with 13-ft side water depth. The gravity thickeners thicken the solids to 2 to 3 percent total solids (TS) before being stabilized in twelve 105-ft-diameter anaerobic digesters, each with a nominal operating volume of 1.5 mil gal.

The digesters are arranged in three clusters of four digesters per cluster, where two digesters per cluster operate as primary digesters and two operate as secondary digesters. Digester Cluster 3 normally operates with two of the digesters acting as sludge storage tanks before dewatering. Digester 9 is located in Cluster 3 and acts as a primary digester that discharges to Digester 10, which acts as a secondary digester. The digested biosolids are further dewatered using four Alfa Laval PM 75000 centrifuges, which achieve 18 to 22 percent TS. The sludge fed to the centrifuges is currently conditioned using a dry polymer-type system.

The CDWWTP, located on Virginia Key, is the oldest existing sewer treatment plant operated by MDWASD and was originally constructed in 1956. The CDWWTP is a high-purity oxygen-activated sludge secondary treatment facility, with a permitted capacity of 143 mgd. The plant has two separate liquid processing streams: Plant 1 is rated at 60 mgd average daily flow (ADF) and Plant 2 is rated at 83 mgd ADF.

The CDWWTP produces only WAS, which is mixed with polymer in the piping and sent to eight 55-ft-diameter gravity thickeners with a 13-ft side water depth. Both Plant 1 and Plant 2 contain four gravity thickeners each. The gravity thickeners thicken the solids to 2 to 4 percent TS before being stabilized in twenty-four 105-ft-diameter anaerobic digesters, each with a nominal operating volume of 1.5 mil gal, operated under two-stage mesophilic conditions. Plant 1 consists of two digester clusters, each with four digesters, and Plant 2 consists of four digester clusters, each with four digesters. The digested biosolids are further dewatered using Alfa Laval DS 706 centrifuges, which achieve greater than 25 percent TS. The sludge fed to the centrifuges is currently conditioned using a dry polymer-type system. Ferric sulfate is also added to the dewatering feed primarily for struvite control.

The CDWWTP also receives primary sludge and WAS from the North District Wastewater Treatment Plant (NDWWTP). The sludge transfer building at NDWWTP houses four sludge transfer pumps with variable speed drives. The pumps are used to pump sludge through two 16-in. force mains. The force mains are parallel for about 10 mi before they join at an interconnection. From the interconnection, sludge can be directed to the sewage collection system of CDWWTP (Force Main #2) or to an extension of one 16-in. force main that continues another 6 mi, where it discharges to the gravity sludge thickeners located at Plant 2 of CDWWTP (Force Main #1). The sludge from NDWWTP contains an exorbitant amount of rags, plastics, and grit, which have historically been problematic for CDWWTP sludge thickening operations. Screening of NDWWTP sludges will be implemented to remedy this operational challenge.

Design Considerations for Sludge Thickening and Dewatering Centrifuges

In general principle, a centrifuge behaves similarly to clarifiers and gravity thickeners in that physical separation of solid from liquid is a result of gravity and can be aided by metal coagulants and organic polymers, which increase particle density and promote flocculation. The advantages of centrifuges to enhance the rate or settling, sludge concentration, and solids recovery is a result of centripetal forces being thousands of times greater than the gravitational force experienced in a clarifier. The hydraulic capacity of a centrifuge can be expressed as a function of the centrifuges dimensions and the acceleration force experienced within the centrifuge due to the speed of rotation of the centrifuge, as shown in Equation 1 (WEF MOP No. 8, fifth edition, 2008).

Equation 1

$$\Sigma = 2\pi l\,(\omega^2/100g)(0.75r_2^2+0.25r_1^2)$$

Where:
Σ = theoretical hydraulic capacity (cm^2);
l = centrifuge bowl's effective clarifying length (cm);
ω = centrifuge bowl's angular velocity (rad/s);
g = acceleration from gravity (m/s^2);
r_1 = radius from centrifuge centerline to the liquid surface in the centrifuge bowl (cm);
r_2 = radius from centrifuge centerline to the inside wall of the centrifuge bowl (cm).

The equation helps in determining the maximum hydraulic capacity for a size of a machine and operational settings. Sizing a facility assists in calculating a minimum number of units to achieve a hydraulic throughput. Unfortunately for design and operations, centrifuge performance is additionally dependent on the input sludge conditions, polymer dose, metal salt dosing, pumping considerations, and other factors. Due to the variability of sludges between treatment plants, even those with the same treatment processes and influent wastewater characteristics that determine the real-world number of centrifuges to successfully process a plant's sludge to both a certain sludge concentration and solids recovery, while managing chemical and power costs pilot testing, is essential (WEF MOP No. 8, fifth edition, 2008).

Pilot Study Overview and Objectives

To better establish performance criteria for the new thickening and dewatering centrifuges, a nearly year-long centrifuge thickening, diges-

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Table 1. Summary of Pilot Testing Phases

Pilot Phase	Objective	Duration SDWWTP Nov.2015-Apr. 2016	Duration CDWWTP May 2016-Sept. 2016	Sample Measurements
Phase 1: Thickening pilot operating with unthickened waste activated sludge (WAS) and primary sludge (CDWWTP only)	Determine centrifuge WAS thickening performance criteria	4 weeks	5 weeks (WAS only) 10 weeks (primary sludge and WAS)	TS – all TSS – centrate
Phase 2: High-rate steady state digestion. Thickening pilot operating with gravity -thickened WAS	Simulate high-rate anaerobic digestion to monitor performance and prepare sludge for Phase 3	18 weeks	10 weeks	TS – all VS/TS – digester feed and digested biosolids pH – digested biosolids
Phase 3: Dewatering pilot operating with anaerobically digested biosolids following Phase 2 thickening	Determine centrifuge dewatering performance criteria with centrifuge-thickened anaerobically digested sludge	7 weeks	3 weeks	TS – all TSS – centrate

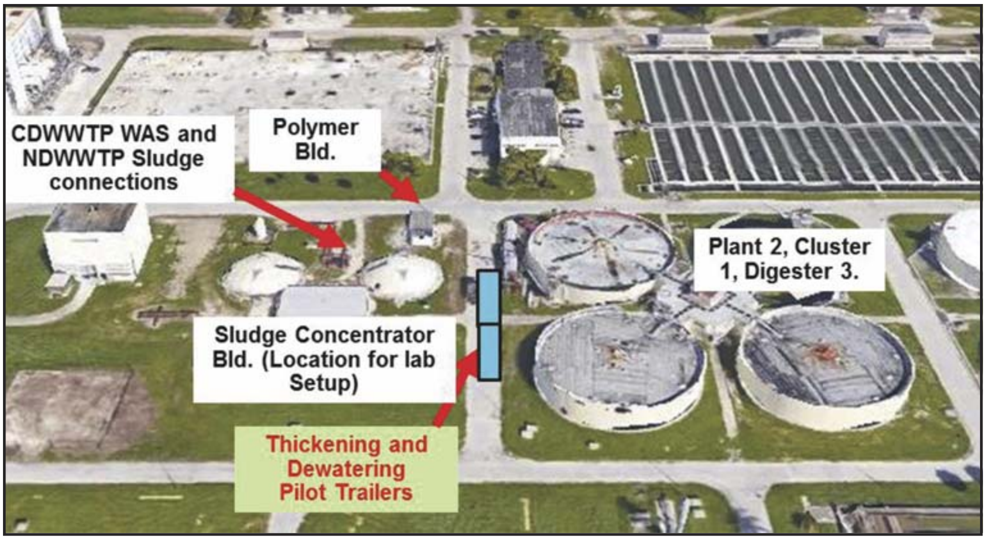

Figure 1. Central District Wastewater Treatment Plant Pilot Site Plan Showing Centrifuge Installation

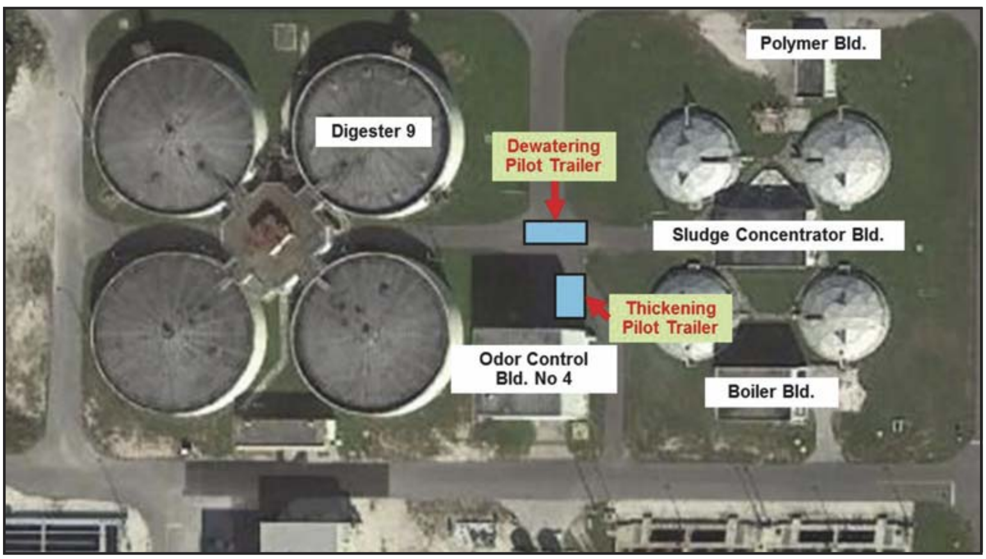

Figure 2. South District Wastewater Treatment Plant Pilot Site Plan Showing Centrifuge Installation

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tion, and centrifuge dewatering pilot study was conducted at SDWWTP and CDWWTP. The pilot study was set up to simulate future thickening, digestion, and dewatering operating conditions to establish thickening and dewatering performance criteria. The pilot operation was conducted in three distinct phases at each plant, as outlined in Table 1, with critical samples taken throughout each phase pertinent to understanding equipment performance and setting design criteria.

Figures 1 and 2 show a plan view layout of the sites and identify the locations for the centrifuge thickening and dewatering pilot trailers. Figure 3 provides photos of the pilot testing trailers, which were selected after a competitive bidding process. The program management and construction management (PMCM) team oversaw the piloting effort, with outstanding support from SDWWTP staff.

Periodic samples collected throughout the pilot operation were all analyzed for TS. During Phases 2 and 3, the PMCM team regularly monitored the volatile solids (VS) content of the thickened sludge fed to the digester and digested biosolids samples. Digested biosolids pH was measured and the centrate samples were analyzed for total suspended solids (TSS). College interns were trained to perform the sampling and laboratory analysis throughout the duration of the pilot testing period.

South District Wastewater Treatment Plant Phase 1: Thickening Pilot Testing

The Phase 1 piloting operation was based on feeding unthickened WAS to the pilot thickening centrifuge. The purpose of the Phase 1 operation was to determine the optimum polymer design conditions and performance of the centrifuge thickening. The

Figure 3. Photos of Pilot Equipment: Thickening (left) and Dewatering (right) *(courtesy of Centrisys)*

overall target for the centrifuge thickening performance, as stated in the basis of design and specifications, was to thicken the WAS to 5.5 percent TS while maintaining greater than 95 percent solids recovery; determining the necessary polymer dose to achieve this performance is also important. Parameters that were adjusted for the centrifuge thickening included the pool depth, bowl speed, and differential scroll speed (Goss, et al.).

Thickening Pilot Testing: No-Polymer Operation

The system initially started up on lower sludge flows, with no polymer injection. Figure 4 summarizes the operation, without polymer, for a medium bowl speed equal to 2,590 revolutions per minute (rpm) and differential speed of 12 rpm, with flow rates ranging from 40 to 100 gal per minute (gpm).

This operation showed that it was possible to thicken the sludge up to 6 percent TS without the use of polymer, but at higher throughputs (above 60 gpm), the solids recovery was sacrificed. The tests were conducted at a deep pool depth, a medium pool depth, and a shallow pool depth. The trend shows that, at the shallowest pool depth, solids recovery improved, but total thickened solids were sacrificed. The thickened solids concentration at the deep and medium pool depths were nearly the same, but it should be noted that the feed solid content was lower when testing the deepest pool depth (0.9 percent TS),while the feed solids were closer to 1.4 percent solids when testing the medium pool depth. If testing was done on the same feed solids concentration, it would be expected that the solids would be thicker at the deepest pool depth.

Results of the testing without polymer indicated that it's possible to maintain the desired thickened TS concentrations without the use of polymer. Although the operation without polymer may sacrifice solids recovery, future operation at this condition may be desired when sludge production is below design capacity, as it could reduce operation and maintenance costs associated with polymer consumption.

Thickening Pilot Testing: Emulsion Polymer Setup and Initial Testing

The pilot unit was set up to allow injection of polymer at two locations, as illustrated in Figure 5, either directly into the bowl of the unit (internal injection) or in the sludge feed line upstream of the centrifuge inlet (external injection). Polymer flow was measured during each sampling event using a calibration column located on the pilot trailer.

The initial polymer used was PRAESTOL® K144-L, which is a cationic, high-molecular-weight emulsion polymer. Polymer dosage, using internal injection, was slowly increased at a constant throughput of 100 gpm, while visually monitoring the clarity of the centrate. The testing was conducted at the shallowest pool depth and a differential speed of 12 rpm. Once polymer was added, the bowl speeds were reduced from 2,590 rpm to between 1,900 to 2,100 rpm to keep the thickened solids from being too thick. The results showed that, with the increased polymer dosages and reduction in bowl speed, the thickened solid content re-

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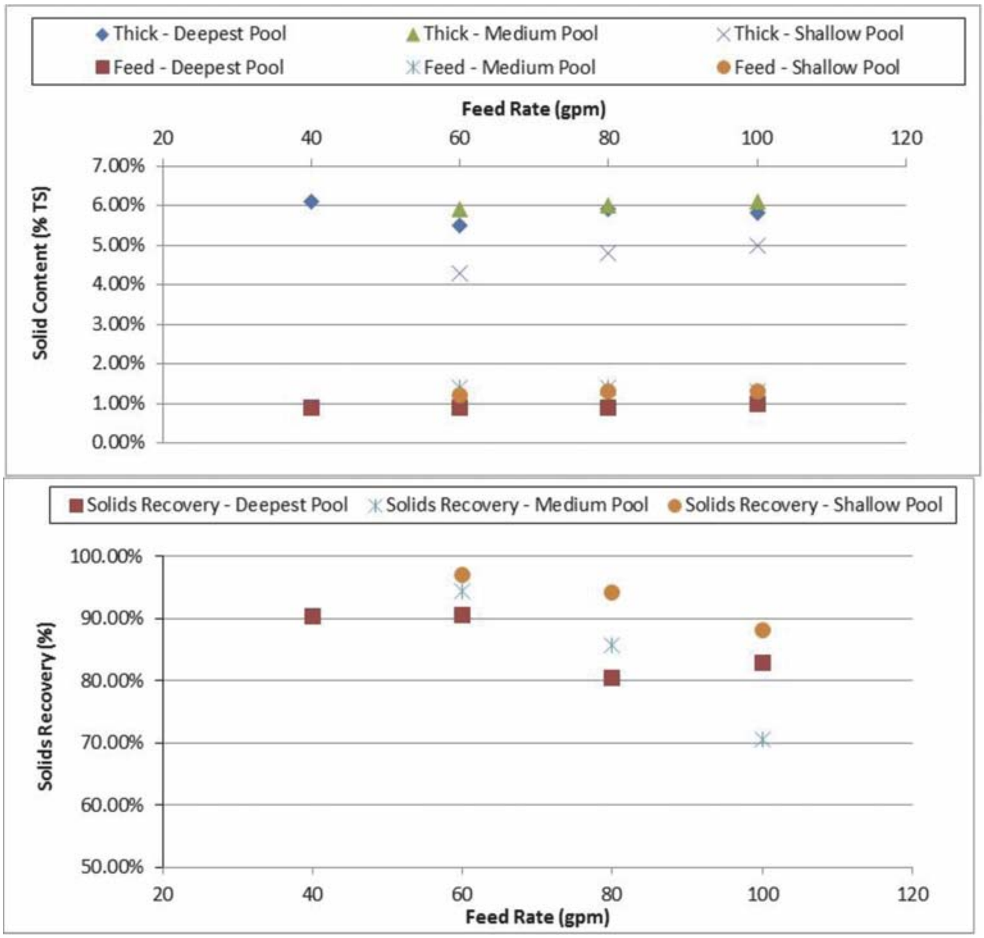

Figure 4. No-Polymer Operation, Medium Bowl Speed (2,590 rpm)

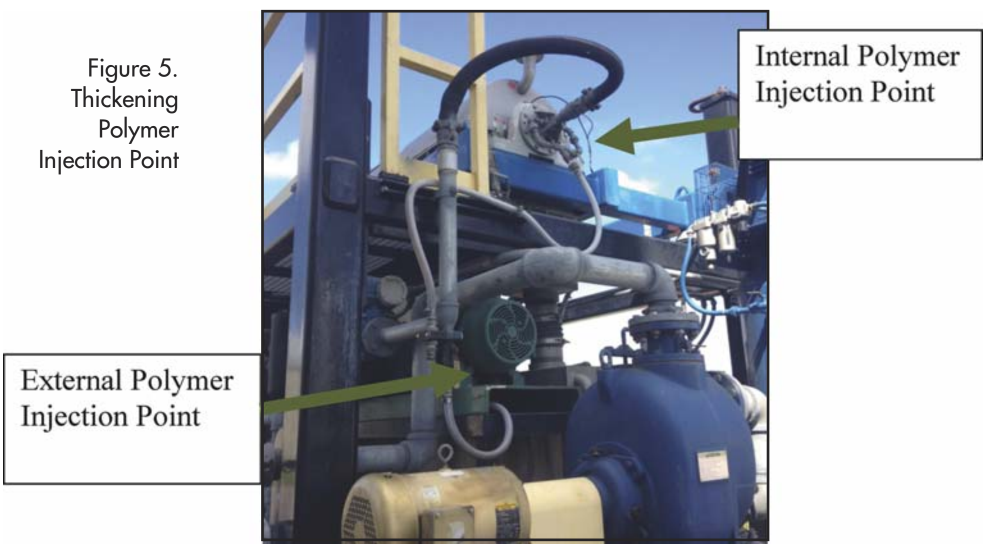

Figure 5. Thickening Polymer Injection Point

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mained steady, but the solids recovery improved.

Once relatively clear centrate was achieved, the flow rate to the machine was increased to maximize throughput, while optimizing solids recovery (based on visual observations of centrate quality). In addition, other cationic, high-molecular-weight emulsion polymers were tested in the machine and optimization testing showed that the polymer worked the best.

Thickening Pilot Testing: Dry Polymer Setup

The Centrisys thickening unit contains an emulsion polymer system and is not set up with the provisions to operate on dry polymer, so a creative solution was required to facilitate testing dry polymer in the pilot centrifuge. In order to allow the testing, one of the SDWWTP polymer makeup systems (not currently in use), was used to make up the dry polymer solution, which was pumped to a tote that was connected to a dedicated portable pump to meter the dry polymer solution into the centrifuge. Photos of the setup are provided in Figure 6. The pump on the trailer used for emulsion polymer was too small to pump the dry polymer solution.

A calibration curve was developed for the polymer pump by a series of bucket tests conducted at different pump speeds and the curve was compared to the theoretical zero pounds per sq in. (psi) pump curve, which showed good convergence. The dry polymer used for testing was Polydyne C-3283, which is the polymer the plant currently uses in its dewatering centrifuges.

Figure 6. Temporary Dry Polymer Setup

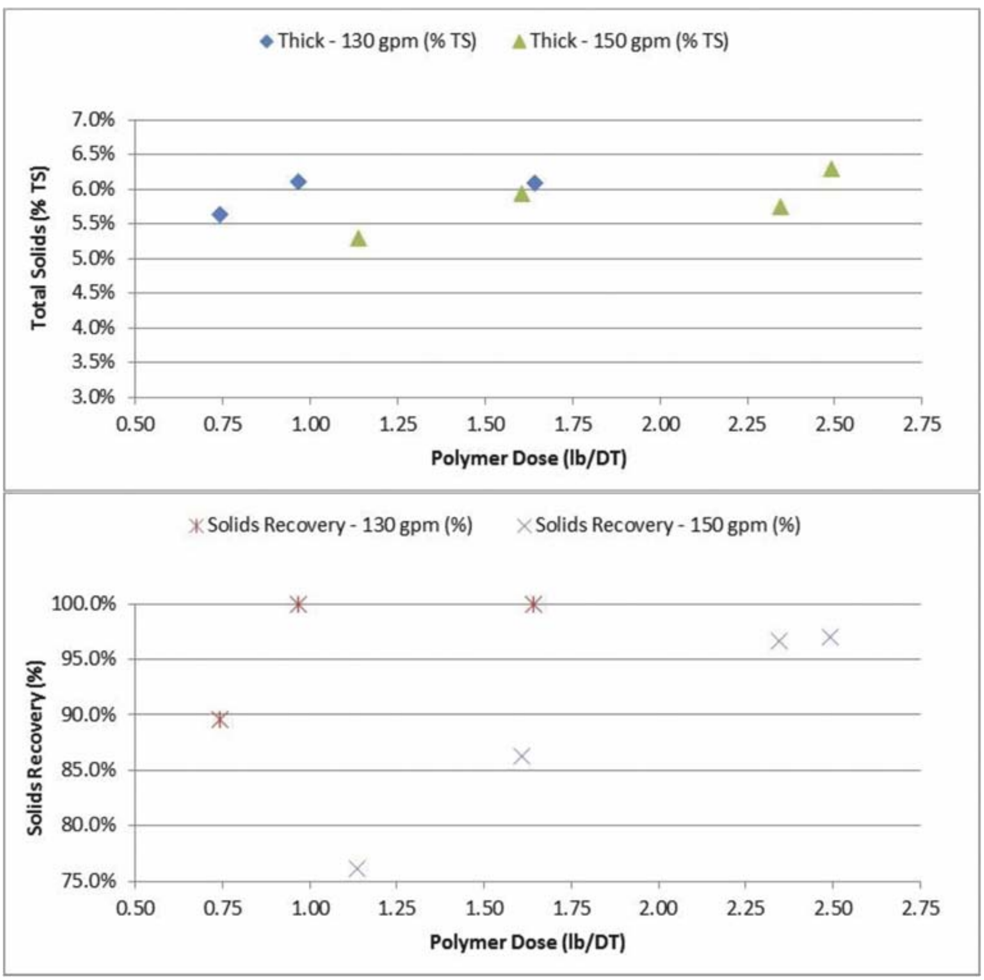

Figure 7. Emulsion Polymer: 130 and 150 gpm WAS Feed, Medium Bowl Speed

Thickening Pilot Testing: Results

Pilot tests were run to further determine results for the centrifuge thickening operation. The results from the optimization trials showed that good performance could be achieved with medium bowl speeds of 2,400 to 2,600 rpm. At a lower flow rate of 100 gpm, an emulsion polymer dose of 1 pound per dry ton (lb/DT) showed good results, but as the flow was increased to 150 gpm, at least 2 lb/DT were needed. The higher polymer dose requirements at higher flows also correlated to the point where external polymer injection provided better results than internal polymer injection.

The polymer curves and flow curves conducted during the performance testing period were to further test the limits for the operational parameters. Additional performance testing was conducted in March 2016 using the plants dry polymer (Polydyne C-3283). The purpose was to repeat the November 2015 testing, but with dry polymer that more closely represents future operation.

Thickening Pilot Testing: Polymer Curve Results

Polymer curve tests were conducted by maintaining a constant volumetric throughput of sludge feed to the centrifuge, but changing the polymer dose to measure the impact. With the exception of changing polymer dose, all other parameters on the centrifuge remained the same for each polymer curve test. In November 2015, three different polymer curves were generated for the 144-L emulsion polymer at 100, 150, and 170 gpm WAS flow rates through the pilot centrifuge. In March 2016, an additional 144-L emulsion polymer curve was conducted at 130 gpm and several dry polymer curves were conducted at 130, 150, and 170 gpm.

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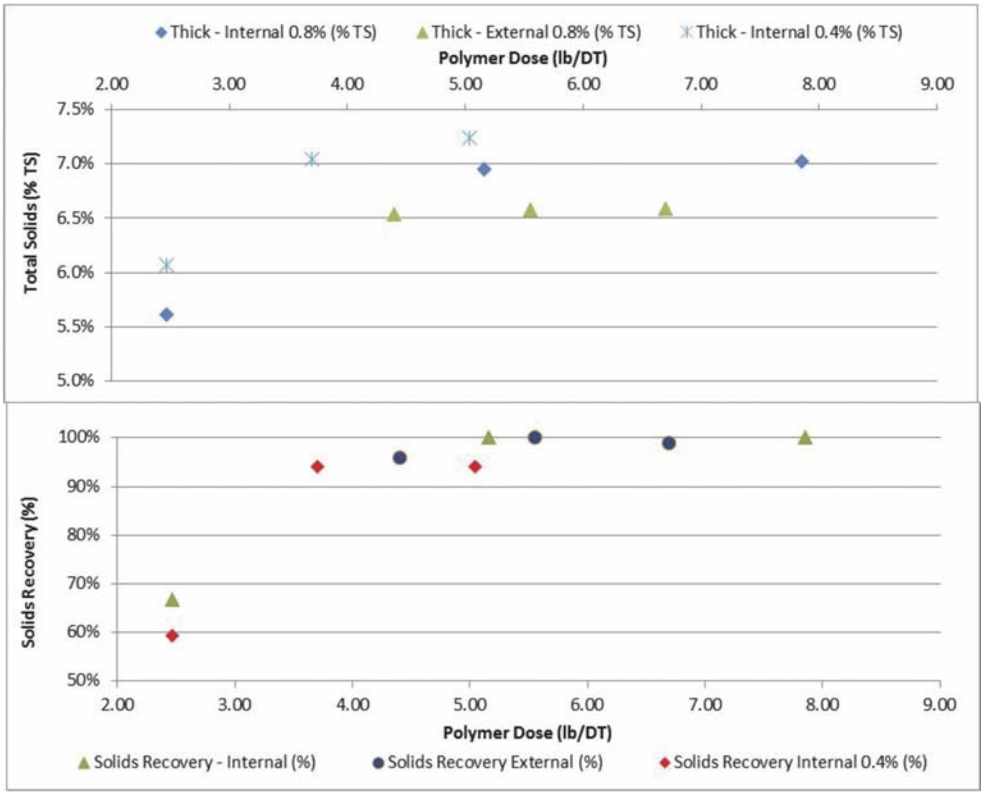

Figure 8. Dry Polymer: 130 gpm WAS Feed, Internal and External Injection, Medium Bowl Speed

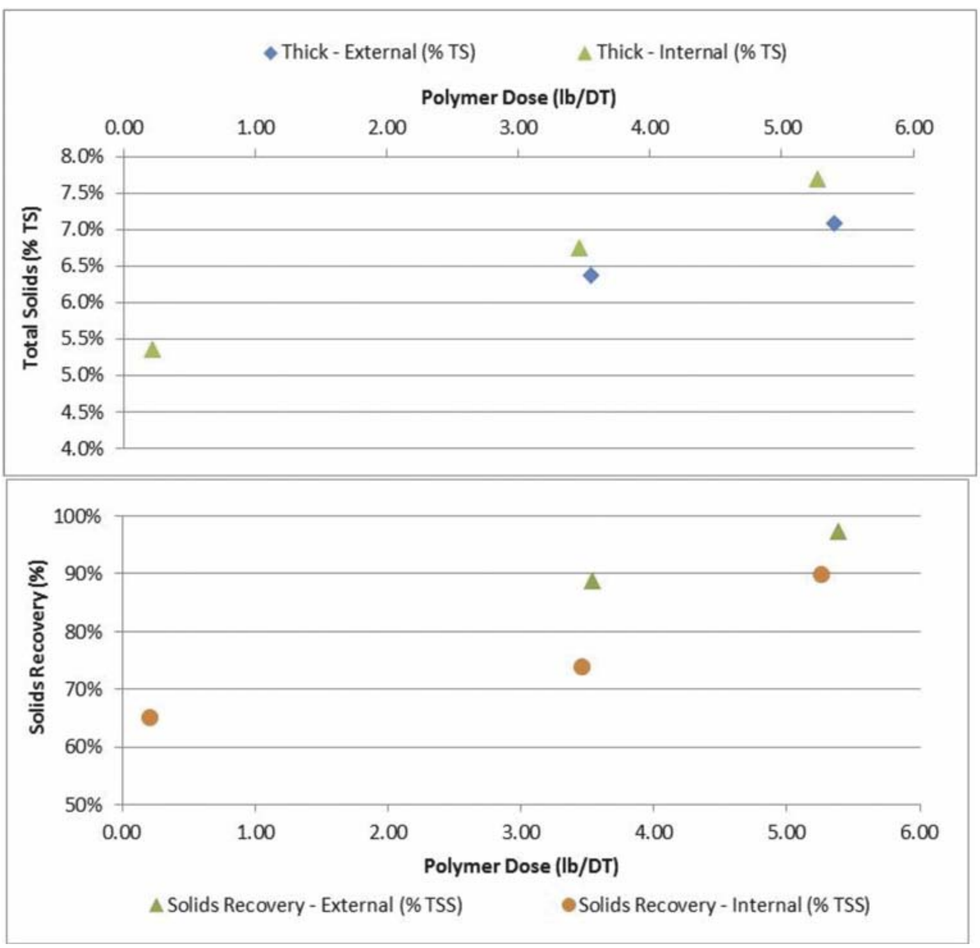

Figure 9. Dry Polymer: 150 gpm, Internal and External Injection, Medium Bowl Speed

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Figure 7 also shows the data for emulsion polymer curves at the 130 and 150 gpm WAS feed, conducted at medium bowl speed (2,400 to 2,600 rpm). At 130 gpm WAS feed, the curve was conducted with internal polymer injection, and at 150 gpm WAS feed, the curve was conducted with external polymer injection. The concentration of the WAS during this testing ranged from 1.1 to 1.5 percent TS.

As shown in Figure 7, at 130 gpm WAS feed with internal emulsion polymer injection and a deep pool depth, good performance is obtained for polymer doses greater than 1 lb/DT active achieving close to 6 percent TS. At polymer doses greater than 1 lb/DT active, close to 100 percent solids recovery was also achieved. Exceeding 1 lb/DT or up to 1.6 lb/DT active did not have much of an impact on the solids concentration or the solids recovery.

At 150 gpm WAS feed, with external emulsion polymer injection and a shallow pool depth greater than 5 percent, TS was achieved for all polymer doses tested. The solids recovery exceeded 95 percent for the two highest dosing points when active dosing was greater than 2.3 lb/DT.

The dry polymer curve for the WAS flow rate of 130 gpm, with both internal and external dry polymer injection, is shown in Figure 8 for a medium bowl speed of 2,586 rpm and deep pool depth. The polymer concentration during these tests was approximately 0.8 percent TS. An additional 130 gpm WAS polymer curve, also shown in Figure 8, used a 0.4 percent TS polymer solution (with internal dry polymer injection) at a bowl speed of 2,408 rpm and deep pool depth. For all tests, the feed averaged 1.2 to 1.4 percent TS.

For internal dry polymer injection with a 0.8 percent TS polymer solution, greater than 5.5 percent TS was achieved for all polymer doses tested; however, only greater than 95 percent recovery was achieved at polymer doses greater than 5 lb/DT. For external dry polymer injection with a 0.8 percent TS polymer solution, the active polymer dose ranging from 4.3 to 6.7 lb/DT did not show significant differences in centrifuge performance in terms of solids content. The thickened solids content ranged from 6.5 to 6.6 percent TS and the solids recoveries were greater than 95 percent for all samples. The TSS sample analyzed for 4.3 lb/DT may also have had an error and it was noted that the centrate was visually dirtier than the samples with high polymer dosages.

For internal dry polymer injection with a 0.4 percent polymer solution, greater than 5.5 percent TS was achieved for all polymer doses tested, and at polymer doses greater than 3.8 lb/DT, the solids recovery was near the 95 percent target. The thickening pilot results show that at 130 gpm WAS feed, approximately 5 lb/DT of the dry polymer is required to maintain greater than 95 percent recovery, but at the settings tested, the thickened sludge exceeds the needed solids content and approaches 7 percent TS. Further optimization would be required to maintain the target of 5.5 percent TS, such as lowering the pool depth.

The dry polymer curves for the WAS flow rate of 150 gpm with both internal and external dry polymer injection is shown in Figure 9 for a medium bowl speed of approximately 2,585 rpm and deep pool depth. The polymer concentration during these tests ranged between 0.7 to 0.8 percent TS. For all tests, the feed averaged 1.2 to 1.3 percent TS.

For internal dry polymer injection, greater than 5 percent TS was achieved for all polymer doses tested; however, none of the points achieved greater than 95 percent recovery. Flocs were observed in the centrate for the external polymer injection testing, so it was evident that this flow was too high for the internal polymer injection to work efficiently. For external injection, greater than 6 percent TS was achieved for all polymer doses tested. The solids recovery, however, was only greater than 95 percent for the highest active polymer dose, which was 5.3 lb/DT. It may have been possible to get more optimal performance (closer to 5.5 percent TS with greater than 95 percent solids recovery) with a shallower pool depth.

Thickening Pilot Testing: Extended Operation Results

After generating the polymer, flow, and bowl speed curves, the unit was operated several days at a constant flow rate with optimized settings to test the stability of the operation throughout the course of a day. During November 2015, these tests were conducted using the 144-L emulsion polymer at a WAS flow rate of 135, 165, and 200 gpm. In March 2016, the extended operation testing with dry polymer was repeated twice at 135 gpm. Samples were collected during these trials approximately once every hour.

The results with emulsion polymer were stable throughout the course of a run, but the results with the dry polymer showed more fluctuation with solid recovery degradation over time. It was planned to again repeat the 135 gpm extended operation testing using the dry polymer; however, the gearbox on the progressing cavity-thickened sludge pump failed before this testing was completed. Due to the lead time to repair it, it was not possible to conduct the additional testing in the schedule for the project. It is believed that limitations in the setup and lack of mixing on the polymer tote contributed to the poor performance for the extended operation testing with dry polymer. The concentration of polymer samples collected throughout the extended run varied between 20 to 40 percent on both days tested.

A comparison of the extended operation at 135 gpm with emulsion and dry polymer is depicted in Figure 10. The runs with dry polymer at 4 to 7 lb/DT active polymer dosages were conducted with a deeper pool depth than the run with emulsion polymer conducted at 2 to 3 lb/DT active polymer dosages. The deeper pool depth is likely the reason the solid content was higher with the dry polymer testing than the emulsion polymer testing. The feed WAS concentration during all three runs ranged from 1.1 to 1.5 percent TS.

The thickening pilot testing showed that the centrifuge could reliably produce solids at 5 to 6 percent TS and achieve greater than 95 percent solids recovery. Testing was conducted using both dry and emulsion polymers. The dry polymer required 5 to 7 lb/DT active dosing compared to 1 to 3 lb/DT active based on the emulsion. It was also possible to thicken the sludge to 5 to 6 percent TS without the use of polymer, but this reduced hydraulic throughput by about 50 percent to allow solids recoveries to remain above 90 percent.

South District Wastewater Treatment Plant Phase 2: Continuous Thickening Pilot Operation

During Phase 2 operation, mechanically thickened sludge was fed to Digester 9 to simulate future high-rate digestion conditions and to increase the solids content of the digested biosolids for the Phase 3 dewatering pilot operations. The feed to the thickening pilot was switched to gravity-thickened sludge to increase solids loading through the thickener to increase the turnover rate in Digester 9. This mode of operation started in December 2015, continued through March 2016, and remained running in parallel with the dewatering piloting conducted in Phase 3. During Phase 2 operation, the thickening centrifuge was fed approximately 100 to 150 gpm of sludge from the gravity concentrator and operated continuously. Figure 11 summarizes the centrifuge performance during the Phase 2 operation. On March 21, 2016, the feed was switched back to the unthickened WAS when the additional thickening testing using dry polymer was conducted.

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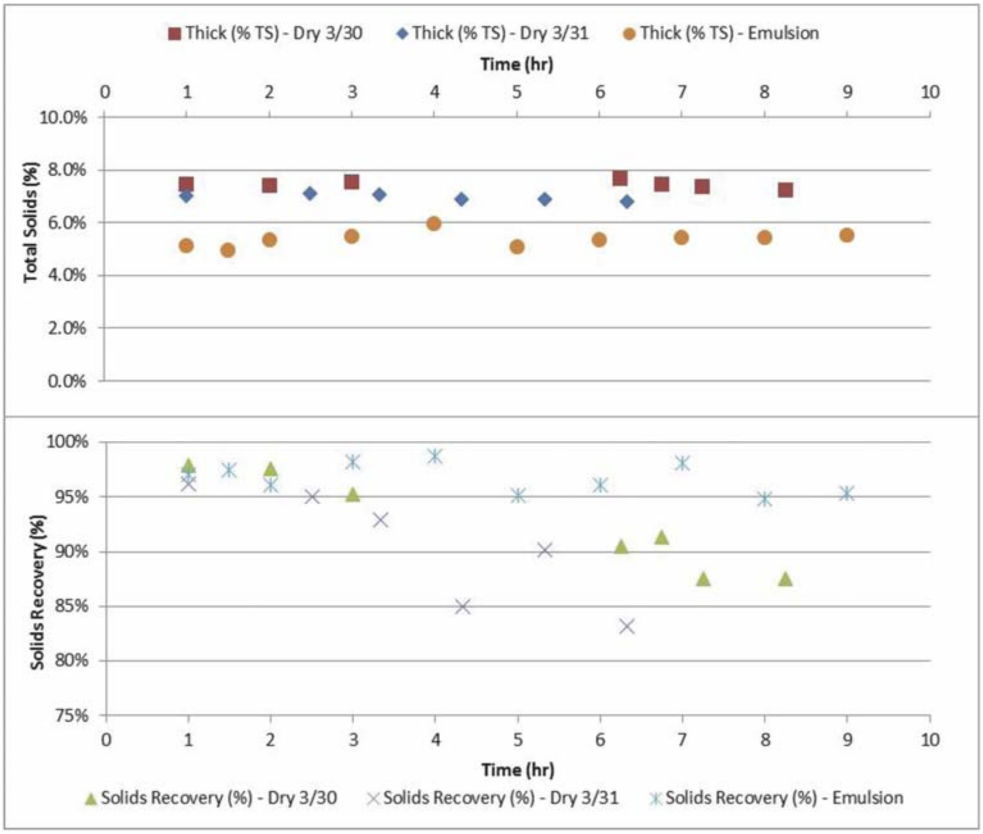

Figure 10. Extended Thickening Operation at 135 gpm

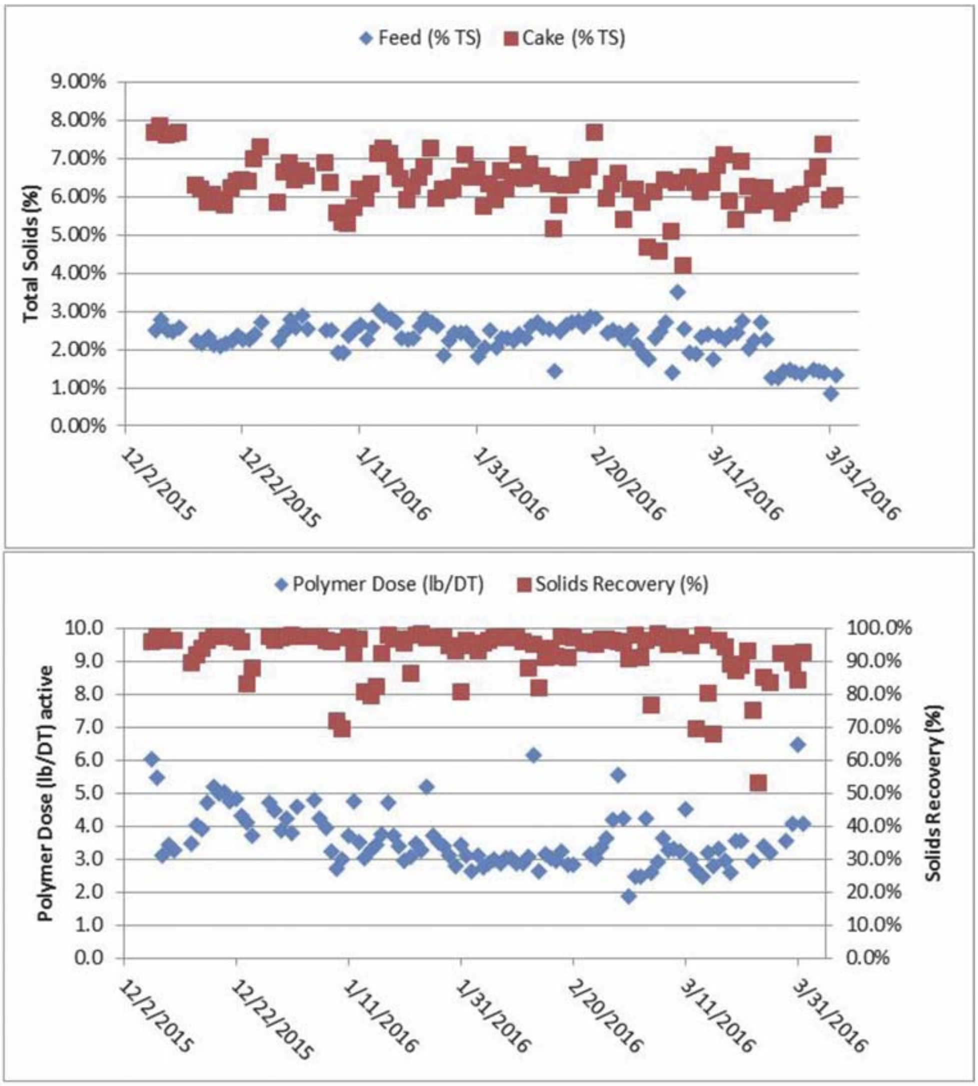

Figure 11. Phase 2 Continuous Thickening Operation

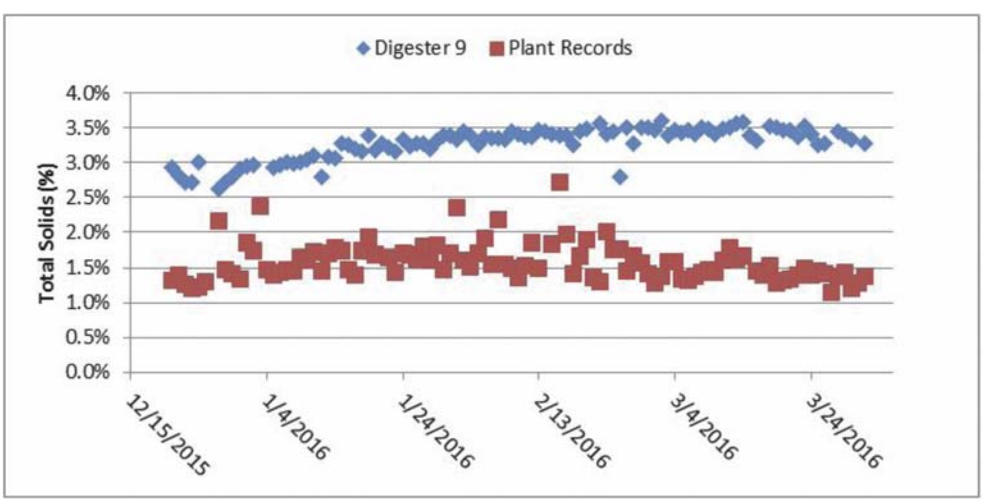

Figure 12. Digester Concentration Comparison, Digester 9 Versus Plant Records

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During Phase 2 operation, the feed from the gravity concentrators averaged 2.2 percent TS, but ranged between 1.5 to 3 percent TS. The concentration in the gravity concentrator measured by the pilot staff compared closely with the concentration based on the plant records. The thickened solids content averaged 6.2 percent TS but fluctuated between 5 to 7 percent TS. During the Phase 1 operation, it was found that the hydraulic pressures inside the machine would increase over time, likely due to grit building up in the machine, and would shut down on an alarm if pressures reached too high of a level. In order to mitigate this, the machine was operated at a lower speed, with higher polymer doses for most of the Phase 2 operation, which allowed for the unit to operate continuously. Weekly cleaning and routine maintenance was conducted throughout the operation.

Throughout the Phase 2 operation, the solids content in Digester 9 was increased to approximately 3.5 percent TS. In comparison during this period, the other operational digesters operated at 1.5 to 2 percent TS, as shown in Figure 12.

During the Phase 2 operation period, Digester 9 averaged approximately 46 percent volatile solids reduction (VSR) with raw undigested sludge averaging 87 percent VS/TS and digested biosolids averaging 77 percent VS/TS. Gas production averaged 16 cu ft (ft^3)/lb VSR throughout the four months of operation. The solids retention time (SRT) in the digesters averaged a little more than 30 days and the solids loading rate (SLR) averaged 0.11 lb VS/ft^3/day.

When comparing the pilot data to the plant's other digesters, the VS feed matched the plant records, but the digester SRT was shorter at approximately 20 days and the digested biosolids VS content was slightly lower with the plants VSR during this period, averaging approximately 42 percent. Thus, it appears that operating digestion with longer SRT and higher thickened sludge increased the VSR by about 4 percent, reducing the biosolids for downstream dewatering and beneficial use.

It was desired to have Digester 9 at a new steady state before starting the dewatering piloting, so dewatering was targeted to start after approximately three digester SRTs had been achieved. Figure 13 confirms that the dewatering performance testing was conducted after three digester turnovers were achieved in Digester 9. The data in Figure 12 showed that the concentration in Digester 9 reached a consistent value of approximately 3.5 percent TS by March 2016.

South District Wastewater Treatment Plant Phase 3: Dewatering Pilot Testing

The purpose of the Phase 3 operation was to determine the optimal design conditions and performance of the dewatering centrifuge using the thickened biosolids fed from Digester 9. The overall target for the centrifuge dewatering performance as stated in the basis of design and specifications was to dewater the thickened digested biosolids to 20 percent TS, while maintaining greater than 95 percent solids recovery. The necessary polymer dose to achieve this performance is also important to determine. The draft specifications indicate that the active polymer dose should be less than 25 lb/DT. Textbook values for anaerobically digested WAS-only biosolids are not readily available, as most anaerobic digesters in the industry digest WAS blended with primary sludge. The Metcalf and Eddy (M&E) fifth edition (2014) lists 16 to 25 percent TS expected for untreated WAS and lists 22 to 25 percent TS expected for anaerobically digested combined WAS and primary. For both untreated WAS and anaerobically digested WAS and primary, the polymer consumption is expected to be 15 to 30 lb/DT active, and solids recoveries are expected to be 95 percent or greater.

Dewatering Pilot Testing: Emulsion Polymer Initial Testing

The initial testing started with emulsion polymers on March 2, 2016. Five cationic, high-molecular-weight emulsion polymers were tested in order to select the most effective two-polymer types for further testing. The emulsion polymers were able to achieve 22 to 25 percent TS. Based on visual observation of cake dryness and centrate quality, Centrisys proceeded with purchasing more of the two-candidate emulsion polymers (PRAESTOL 274 FLX and 290 FLX).

Dewatering Pilot Testing: Dry Polymer Setup

The centrifuge trailer has a dry polymer feeding system that was rarely used and required some effort to make it functional. The polymer blending system did not provide adequate mixing of the dry polymer and left unmixed and residual portions of polymer in the tank; the dry polymer feed pump, however, provided suitable control to deliver a dry polymer solution to the centrifuge. The SDWWTP also had a dry polymer makeup system that was no longer used, but was functional. Initially, dry polymer solution was metered from the plant's makeup system directly to the dewatering centrifuge; however, the plant's polymer pumps

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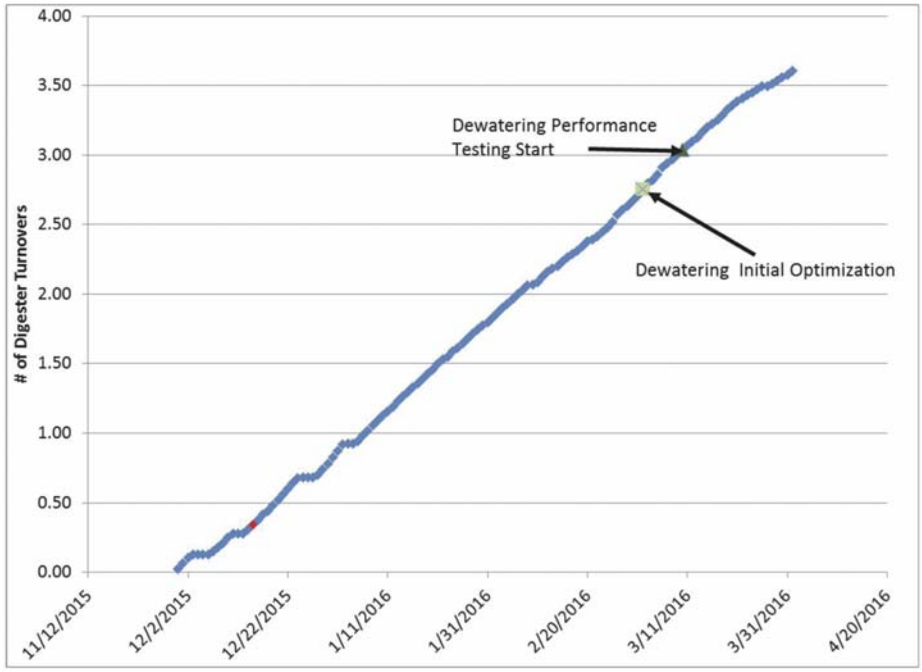

Figure 13. Digester 9 Turnover Progress During Phase 2 Operation

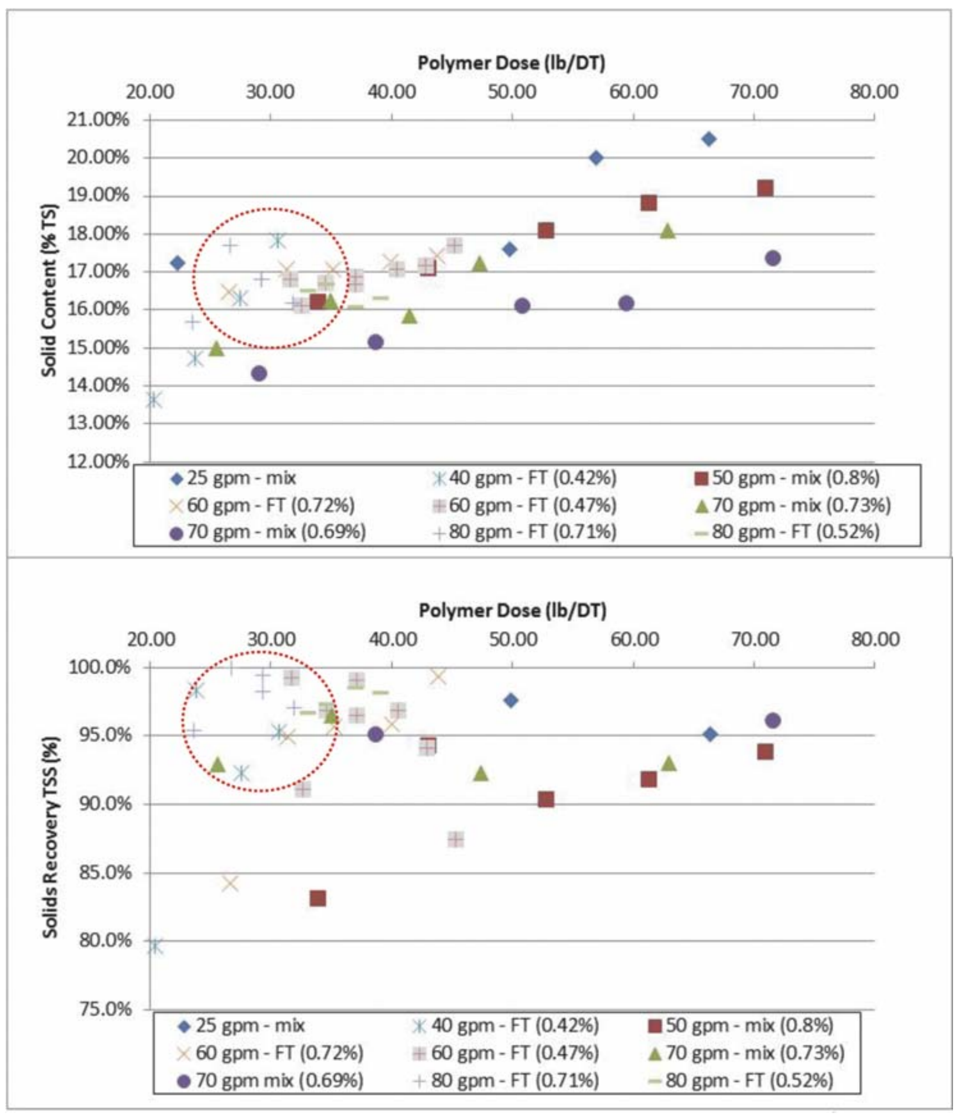

Figure 14. Compiled Dry Polymer Curves from Digester 9

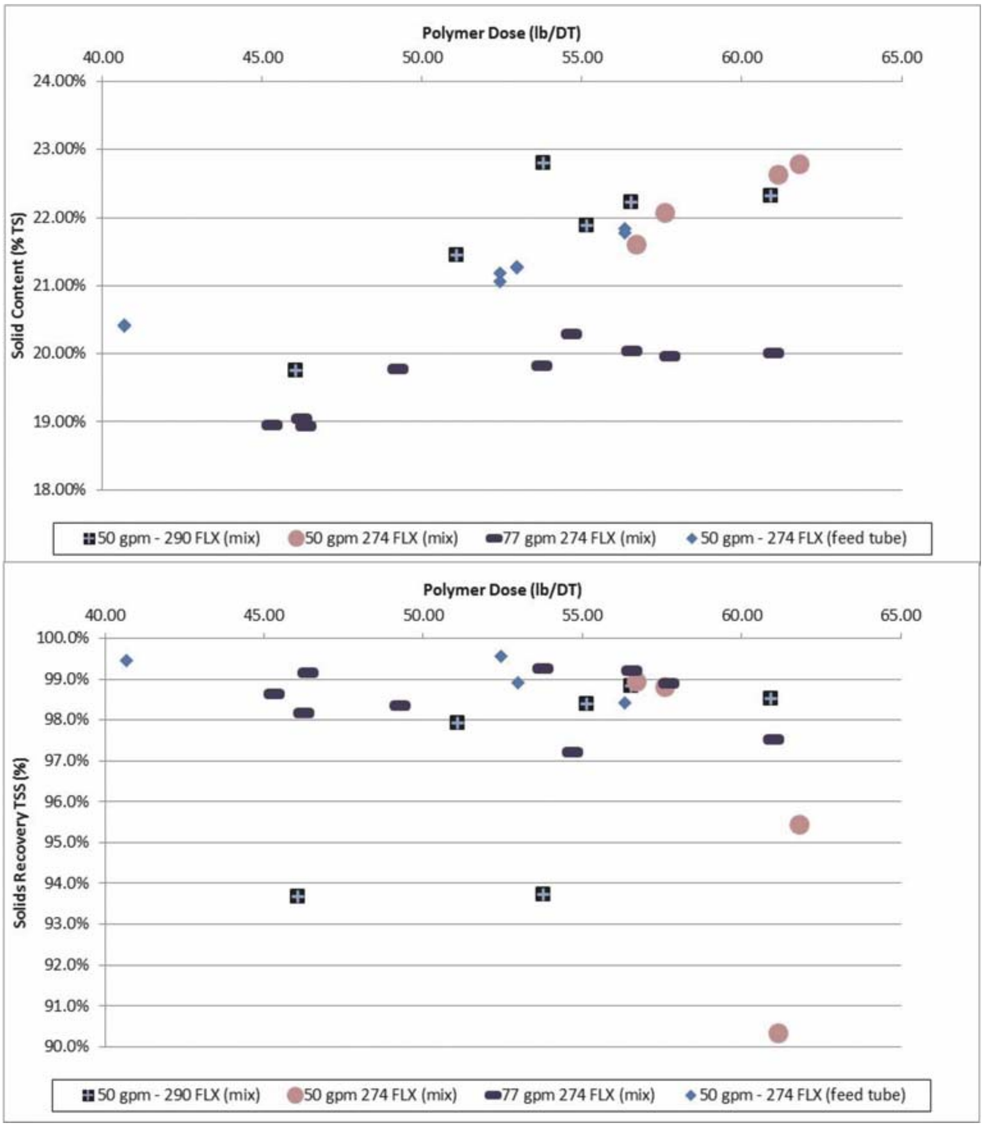

Figure 15. Compiled Emulsion Polymer Curves from Digester 9

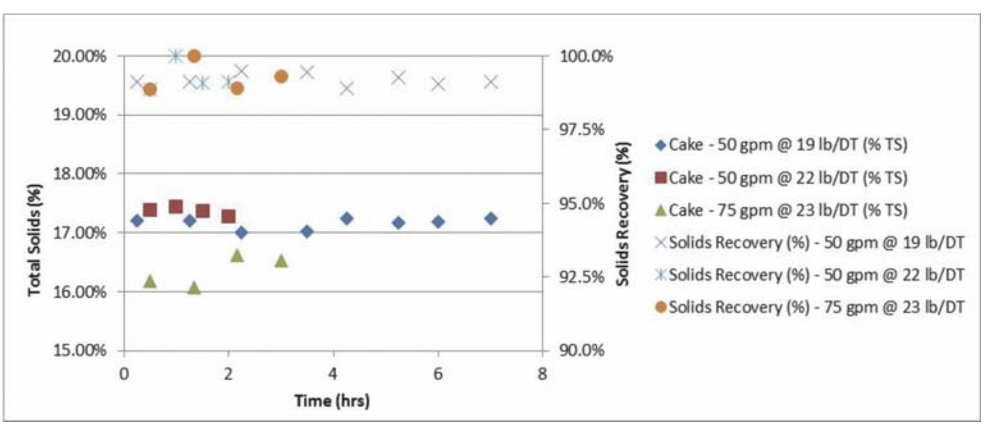

Figure 16. Extended Operation Using Dry Polymer

Continued from page 39

could not adequately control the polymer feed for testing.

In order to conduct the testing, a hybrid of both systems was used. A polymer solution that was made up using the plant's system was pumped into the dry polymer solution hopper on the Centrisys pilot dewatering centrifuge. The Centrisys pump was then used to meter the polymer to the centrifuge. The dry polymer used for the dewatering testing was Polydyne C-3283, which is currently used for SDWWTP dewatering centrifuges.

Dewatering Pilot Testing: Polymer Injection Location Optimization

Polymer injection location in the biosolids is important in getting proper biosolids flocculation for the desired dewatering. Several injection locations were tested using the plant's dry polymer. A mixed injection system, which included dosing a portion of the polymer in a static mixer in the interconnecting hose and the rest of the polymer injected at the grinder on the pilot trailer, was initially found to be the best method for polymer injection based on visual observations of the centrate clarity. Later testing found that injecting polymer directly into the feed tube of the centrifuge provided better centrate quality. The first few weeks of testing were based primarily on the mixed polymer injection and the later testing was conducted using primarily the feed tube injection point.

Dewatering Pilot Testing: Polymer Curve Results

Polymer curve tests were conducted by maintaining a constant volumetric throughput of digested biosolids feed to the centrifuge by changing the polymer dose to measure the impact. With the exception of changing polymer dose, most of the other parameters on the centrifuge remained the same for each polymer curve test. During some of the tests, however, the differential speed was adjusted to increase cake solids, while still trying to maintain good-quality centrate based on visual observations. Testing showed that reducing the differential speed would increase cake solids, but could sacrifice centrate quality and solids recovery.

Polymer curve tests were conducted using both emulsion and dry polymer with both mixed and feed tube polymer injection. All of the dry polymer curves conducted on thickened biosolids from Digester 9 are presented in Figure 14 and the data depict the injection point and polymer concentration.

For the majority of the dry polymer testing, the targeted polymer concentration was 0.8

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percent, but actual concentrations were measured daily throughout testing, and solution concentration appeared to vary from day to day. In addition, the team conducted testing with a more dilute dry polymer concentration. The red circle in Figure 14 denotes the area targeted for optimization with dry polymer. All of the emulsion polymer curves conducted on thickened biosolids from Digester 9 are presented in Figure 15.

The polymer testing curves showed that SDWWTP digested biosolids did not dewater to the level anticipated in the preliminary design (>20percent TS) at active polymer doses of 25 lb/DT. Using the plant's dry polymer (Polydyne C-3283), it was difficult to dewater to greater than 18 percent TS unless the active polymer dose was above 50 lb/DT. Dryer cake could be produced using emulsion polymer, but high polymer doses were also required. For the dry polymer, using feed tube injection versus the external or mixed injection allowed for lower polymer doses, while still maintaining recoveries above 95 percent.

Dewatering Pilot Testing: Extended Operation Results

In addition to polymer curve tests, the dewatering centrifuge was operated several days at a constant flow rate to test the stability of operation throughout the course of a day. Three tests were conducted at 50 gpm: two with dry polymer and one with 274-FLX emulsion polymer. Two tests were conducted at 75 gpm: one with dry polymer and one with 274-FLX emulsion polymer.

The extended runs using dry polymer are shown in Figure 16. The data showed stable performance with high recoveries (>98 percent) for lower active polymer doses of 19 to 23 lb/DT, as compared to results from the polymer curve testing. The dewatered cake solids during the extended operation tests averaged 17 to 17.5 percent TS at 50 gpm feed flow, with 19 to 22 lb/DT active polymer dose. At 75 gpm, with an active polymer dose of 23 lb/DT, the dewatered cake solids averaged 16 to 16.5 percent TS.

The extended runs using emulsion 274 FLX polymer are shown in Figure 17. The data showed stable performance with high recoveries (>96 percent) for active polymer doses of 37 to 44 lb/DT. The dewatered cake solids during these tests averages 20.5 to 21 percent TS at 50 gpm feed flow, with 44 lb/DT active polymer dose. At 75 gpm, with an active polymer dose of 37 lb/DT, the dewatered cake solids averaged 19.3 to 19.6 percent TS.

The Phase 3 dewatering testing showed that 16 to 18 percent TS cake could be achieved with 20 to 30 lb/DT active dosing of dry polymer. The pilot testing showed that the dewatered cake solids were lower than the preliminary design value of 20 percent TS, with a presumed 25 lb/DT active polymer when using dry polymer. Dryer cake at 20 to 22 percent TS could be produced using emulsion polymer, but required higher dosages above 40 lb/DT active.

The Struvite Complex

Struvite accumulation and fouling has historically been one of the major maintenance issues for SDWWTP operations, consuming resources for continuous pipe cleaning to maintain steady, uninterrupted operation of the existing digestion and dewatering process. Struvite is magnesium ammonium phosphate ($MgNH_4PO_{4(s)}$ or MAP) and results from high-soluble orthophosphate concentrations in the digested biosolids when adequate ammonia and magnesium are present.

The potential for struvite formation is expected to increase in the future, with improved thickening prior to anaerobic digestion; moreover, increasing the orthophosphate concentration in the biosolids has been reported to reduce dewatering performance in terms of lower cake solids and higher polymer dosing requirements (Kopp et al., 2016).

Goss et al. (2017) presented the results from the centrifuge thickening piloting, digestion high-rate piloting, and centrifuge dewatering piloting at SDWWTP. The SDWWTP Digester 9 was isolated to receive mechanically thickened sludge (from a pilot-thickening centrifuge) to simulate future high-rate anaerobic digestion. The digester was operated in this manner to allow it to reach a steady state with mechanically thickened sludge. The solids content in Digester 9 was increased from 2 to 2.5 percent TS to approximately 3.4 to 3.5 percent TS.

Once three digester SRT turnovers were achieved in Digester 9, pilot centrifuge dewatering testing was conducted, but the results showed that only 18 percent TS could be achieved, with active dry polymer dosages of 20 to 30 lb/DT. The initial goal was to achieve greater than 20 percent TS, with greater than 95 percent solids recovery, using an active dry polymer dose of less than 25 lb/DT.

Since it was desired to improve dewatering and mitigate the maintenance issues associated with struvite fouling, SDWWTP staff evaluated methods for struvite control, which could also enhance dewatering. In the AirPrex® process, struvite is crystallized directly from the biosolids stream from an anaerobic digester prior to dewatering. The precipitation of struvite prior to dewatering is one potential method to achieve both improved dewatering and reduced maintenance costs. The objective of the pilot study presented here was to demonstrate the technology at SDWWTP and document the struvite precipitation and centrifuge dewatering performance results. The AirPrex pilot testing was conducted after a series of thickening, digestion, and dewatering pilot testing was completed at SDWWTP (Goss et al., 2017).

Background on Struvite Formation

Precipitation from MAP is a common problem in wastewater treatment plants, which can foul piping and equipment. Struvite typically forms in plants that contain anaerobic digesters with upstream biological phosphorous removal. Struvite precipitation occurs when the release of orthophosphate and ammonia from cell hydrolysis during anaerobic digestion reacts with magnesium ions at pH conditions that are conducive for struvite formation (pH of 7.5 to 10). Struvite accumulation tends to occur at locations where pressure is low and carbon dioxide (CO_2) is released from the solution, thus

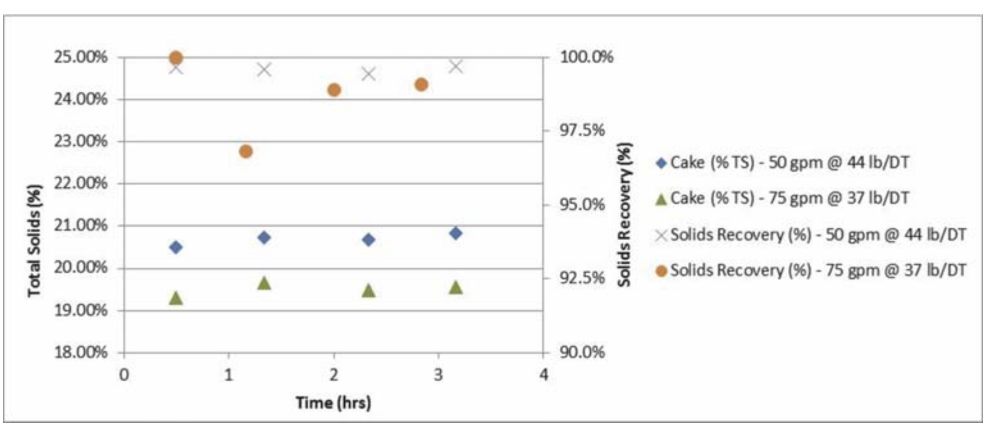

Figure 17. Extended Operation Using Emulsion Polymer

increasing the pH. Unwanted struvite fouling has traditionally been solved by manual cleaning, dilution, and dosing an iron salt to precipitate the phosphorous, or using an antiscaling agent to lower the pH.

The following chemical equation dictates struvite formation (Snoeyink et al.):

Equation 2

$$MgNH_4PO_4{*}6H_2O \leftrightarrow Mg_2^{+} + NH_4^{+} + PO_4^{3-} + 6H_2O \qquad pK_{SO} = 12.6$$

Under these conditions, the activities $\{Mg_2^{+}\}\{NH_4^{+}\}\{PO_4^{3-}\}$ can increase above the solubility product or solubility equilibrium, defined at KSO, causing struvite precipitation. The common places for struvite accumulation are locations where pressure is low and CO_2 is released from the solution, thus increasing the pH (Snoeyink et al.).

For every kilogram of phosphorus recovered, 7.9 kilograms of dry struvite are produced. Typically, magnesium concentration in the wastewater or in the anaerobic digester is at a lower molar ratio than the phosphorous, so magnesium is generally the limiting reagent for unintended struvite formation; therefore, the addition of a magnesium salt is required and a common feature of most controlled struvite precipitation and removal processes.

AirPrex Process

The AirPrex process was developed and patented by Berliner Wasserbetriebe (Germany) in collaboration with the Berlin Institute of Technology. In this process, struvite is crystallized directly from the biosolids stream out of an anaerobic digester, rather than from centrate, as is the case with more-developed struvite crystallization processes, such as the Ostara Pearl process. A general process flow diagram for the AirPrex process is provided in Figure 18.

AirPrex Piloting at South District Wastewater Treatment Plant

The AirPrex piloting was conducted in April 2016 and the AirPrex-treated biosolids were dewatered using a pilot dewatering centrifuge. The reactor was equipped with aerators that strip out CO_2 to increase the pH to between 7.9 and 8.2. The aeration also provides circulation of the struvite crystals inside the reactor, which grow until they reach a sedimentation point and settle to the bottom of the cone-shaped reactor. Magnesium chloride was also dosed to the reactor as a 30 percent liquid solution and the dosing was set to be proportional to the orthophosphate concentrations and biosolids flow. For the pilot operation, the mag-

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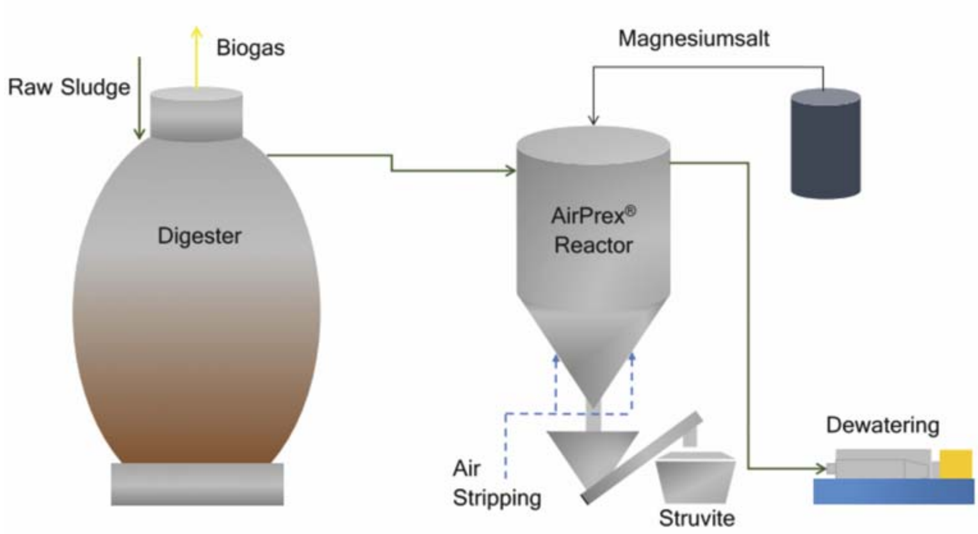

Figure 18. Typical AirPrex Process Flow Diagram *(Courtesy of CNP Corp.)*

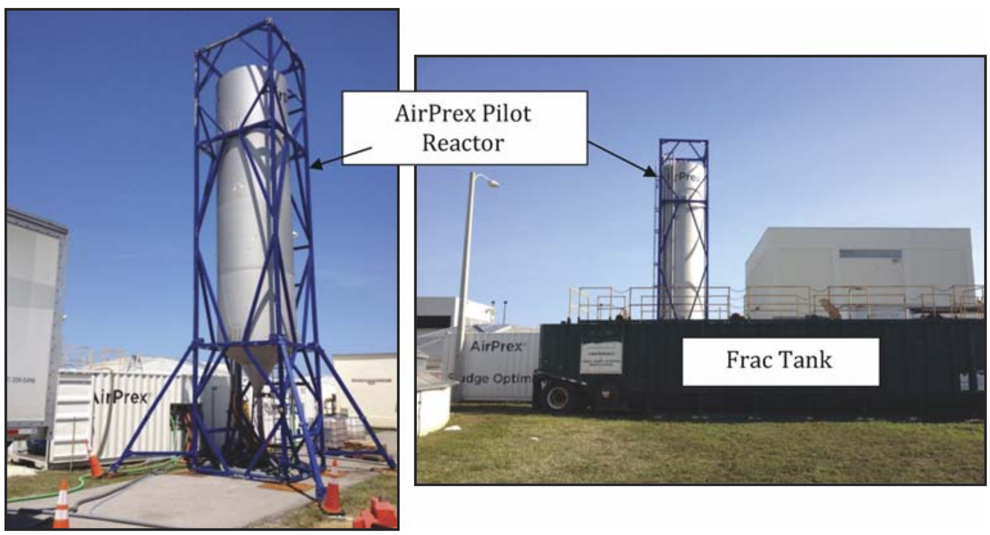

Figure 19. AirPrex Pilot and Frac Tank

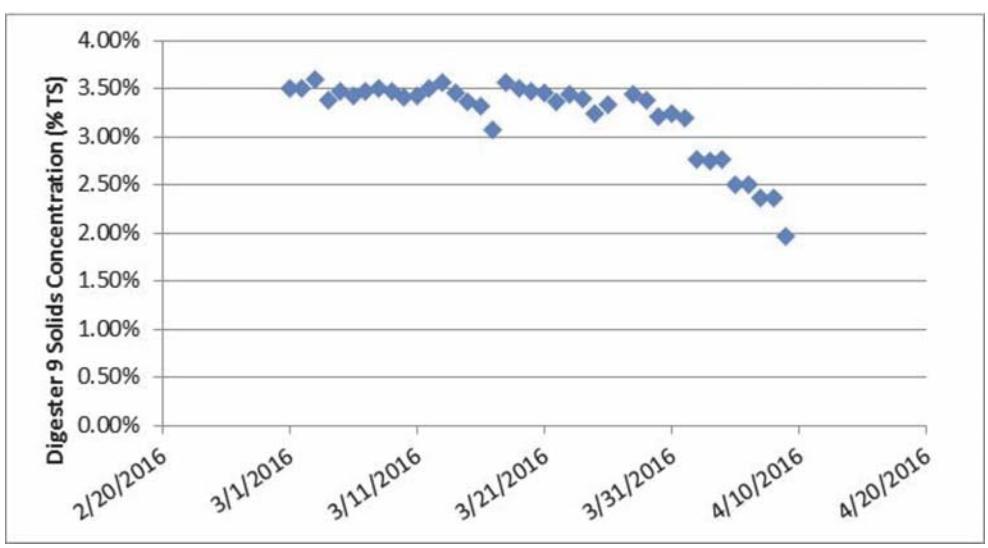

Figure 20. Digester 9 Solids Concentration

Table 2. Summary of AirPrex Performance Data

	Inflow (mg/L)	Outflow (mg/L)	Reduction
Orthophosphate			
Average for entire test	202.3	18.7	90.7 percent
Digester 9	197.9	18.2	90.8 percent
Digester 10	206.1	19.0	90.8 percent
Ammonia			
Average for entire test	1,862	1,597	14.2 percent
Digester 9	1,648	1,408	14.6 percent
Digester 10	2,049	1,716	16.3 percent

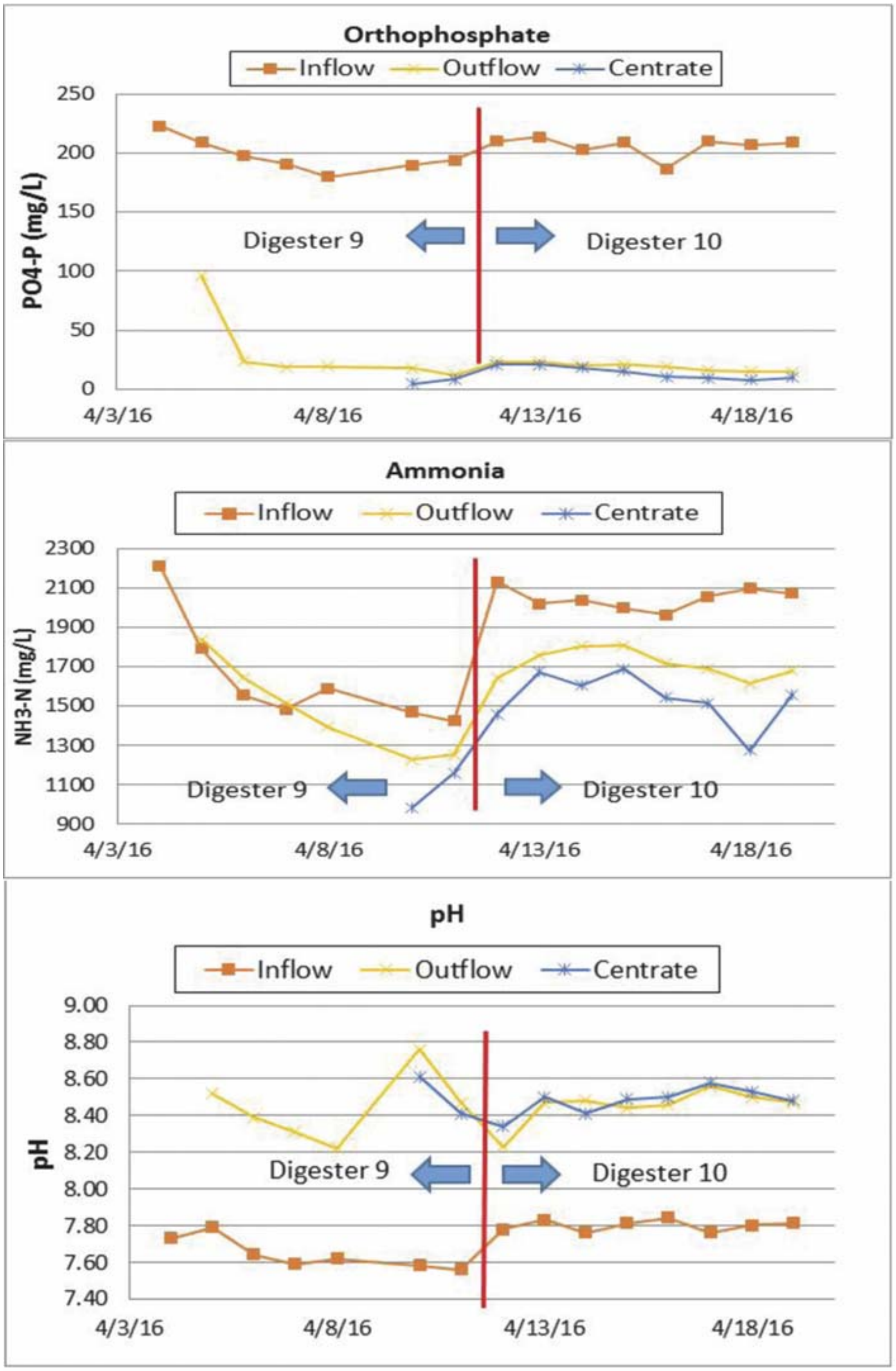

Figure 21. AirPrex Nutrient and pH Monitoring

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nesium chloride dosing rate was set at 1.8 gal per 1,000 gal of digested biosolids (Stitt et al., 2017).

During the pilot period, the AirPrex unit operated continuously, with a digested biosolids flow that ranged from 8 to 12 gpm, and the treated sludge was stored in a mobile frac tank equipped with mechanical mixers that provided a buffer and storage between the AirPrex system and pilot centrifuge. The frac tank was filled continuously during operation, but since the dewatering pilot throughput was up to four to 10 times the flow rate of the AirPrex pilot, the pilot dewatering unit needed about two to four hours of operation time to empty the frac tank. Photos of the pilot unit reactor and frac tank are provided in Figure 19.

The feed to the dewatering pilot was set up to allow testing of both the AirPrex and non-AirPrex-treated digested biosolids in the same day, which allowed for consecutive testing to be conducted to determine the impact of the technology on the dewaterability of the digested biosolids. The objective of the demonstration was to verify the performance of the technology in terms of:

- Percent of orthophosphate removal from the digested biosolids
- Change in dry cake solids against the baseline
- Change in polymer consumption compared to the baseline
- Ability to generate MAP (struvite) that can be recovered

Specified dewatering requirements were to achieve greater than 20 percent TS, with greater than 95 percent solids recovery at an active polymer dose of 25 lb/DT or less (MWH, January 2016).

The AirPrex reactor was first fed digested biosolids from Digester 9 on April 4, 2016, and the dewatering centrifuge first started processing AirPrex-treated biosolids on April 5, 2016. Digester 9 was chosen since it was being operated as a pilot digester, which was receiving mechanically thickened sludge for four months prior to the start of testing. The first week of dewatering operation was performed to optimize the dewatering centrifuge for the AirPrex-treated biosolids. After a few days of operation, however, it was noted that the feed solids to the centrifuge from Digester 9 were decreasing rapidly. It was found that a flush valve was left open for several days that allowed water to fill Digester 9, diluting the digester.

Based on the trend shown in Figure 20, it appears that dilution started at the end of March 2016, reducing the concentration in Digester 9 from 3.3 to 3.5 percent TS down to 2 percent TS. Because of the dilution, the feed to the AirPrex reactor was switched from Digester 9 to Digester 10 on April 12, 2016. Digester 10 was acting as a secondary digester that was receiving only mechanically thickened digested sludge from Digester 9 and the concentration in the digester was steady at approximately 2.5 percent TS.

AirPrex Performance Data

Daily sampling was conducted from the AirPrex reactors to monitor the orthophosphate and ammonia concentrations, as well as the pH of the inflow feeding the AirPrex unit and the outflow, which fed the frac tank (and was the feed for the AirPrex-treated biosolids dewatering testing). Centrate samples from the dewatering unit were also collected for a period of time to monitor both ammonia and orthophosphate concentrations, as well as pH. Figure 21 summarizes the data monitored during the AirPrex testing, and a vertical red line was added to the figures to depict the point where the feed to the AirPrex unit was switched from Digester 9 to Digester 10.

The data did not show a large difference in the orthophosphate concentrations when switched from Digester 9 to Digester 10; however, the ammonia concentration in Digester 9 decreased over time, as the digester was diluted. When switching to Digester 10, both the ammonia concentration and the pH of the inflow biosolids increased. When operating with feed biosolids from Digester 9, the pH averaged 7.6, but when switched to Digester 10, the pH averaged 7.8. The results from Figure 21 also show that the centrate orthophosphate and ammonia concentrations, as well as the pH, measured similar values and followed the trends of the AirPrex outflow biosolids.

After the first day of AirPrex operation, the process was optimized and approximately 91 percent orthophosphate reduction was maintained throughout the pilot reactor (ranging from 89 to 93 percent), reducing the concentration from approximately 200 mg/L down to less than 20 mg/L. In addition, the AirPrex process also provided a 14 to 16 percent reduction in ammonia concentration. Table 2 provides the average orthophosphate and ammonia concentrations in and out of the AirPrex pilot reactor throughout the test. The data broken down for the period when testing was conducted from Digester 9 and Digester 10 are also presented in Table 2.

From the reactor, the struvite collected in the cone was sent to a grit washer, but limitations in the pilot setup showed that the struvite recovered was in a crude form and present with sludge and other debris. Pictures of the struvite product are provided in Figure 22. Furthermore, the grit washer was located in the test trailer beside the reactor and the struvite had a tendency to accumulate in the interconnecting hose. The grit washer was also oversized for the application, so some seed sand had to be added to provide enough pressure for the auger's pressure sensor to be activated. For a full-scale application, the grit washer would be placed directly underneath the reactor and more time would be available to seed the system with struvite.

Figure 22. Recovered Struvite Product

Table 3. Summary of Dry Polymer Curve Tests from Digester 10

Flow (gpm)	Test With AirPrex			Test Without AirPrex		
	Feed (percent TS)	Polymer (percent TS)	Date	Feed (percent TS)	Polymer (percent TS)	Date
45	2.40percent TS	0.44percent TS	4/16/16	2.45percent TS	0.46percent TS	4/15/16
60	2.48percent TS	0.43percent TS	4/13/16	2.40percent TS	0.43percent TS	4/13/16
80	2.54percent TS	0.43percent TS	4/13/16	2.42percent TS	0.42percent TS	4/14/16

Table 4. Optimal Settings for Flow Based on the Polymer Curves from Digester 10

Flow (gpm)	AirPrex				No AirPrex			
	Cake (percent TS)	Solids Recovery (percent)	Polymer (lb/DT)	Differential Speed (rpm)	Cake (percent TS)	Solids Recovery (percent)	Polymer (lb/DT)	Differential Speed (rpm)
45	23 percent	93.9 percent	31.1	1.4	20.4 percent	95 percent	29.8	2
60	21.5 percent	93.8 percent	32	2.2	18.7 percent	96.9 percent	29.7	3.3
80	20.8 percent	95.6 percent	30.9	3.1	18.4 percent	96.5 percent	28.7	4.1

Dewatering Results

The majority of the dewatering testing with Airprex was conducted with the same dry polymer used in the plant's existing dewatering centrifuges and previously used in the dewatering tests (Polydyne C-3283) at a targeted concentration of 0.4 percent TS. Some additional testing was also conducted with Polydyne emulsion polymer based on recommendations from onsite jar testing.

The first week of dewatering operation, using sludge from Digester 9, was performed to optimize the machine for the AirPrex treated biosolids, but because of the dilution issue, the results could not be directly compared to the previous pilot dewatering testing conducted without AirPrex pretreatment. Optimization included adjusting pool depths, bowl speeds, differential speed, and polymer dosing. The initial dewatering results were, however, promising and results of greater than 21 percent TS were being achieved, compared to 18 percent TS prior to starting the AirPrex pilot.

Because of the dilution in Digester 9, it was decided to conduct sequential testing with and without AirPrex-treated digested biosolids to gauge the impact of the technology on dewaterability of SDWWTP digested biosolids. Since the concentration in Digester 9 was diluted, the feed to the AirPrex unit and to the pilot centrifuge was switched from Digester 9 to Digester 10 on April 12, 2016, and the remainder of the

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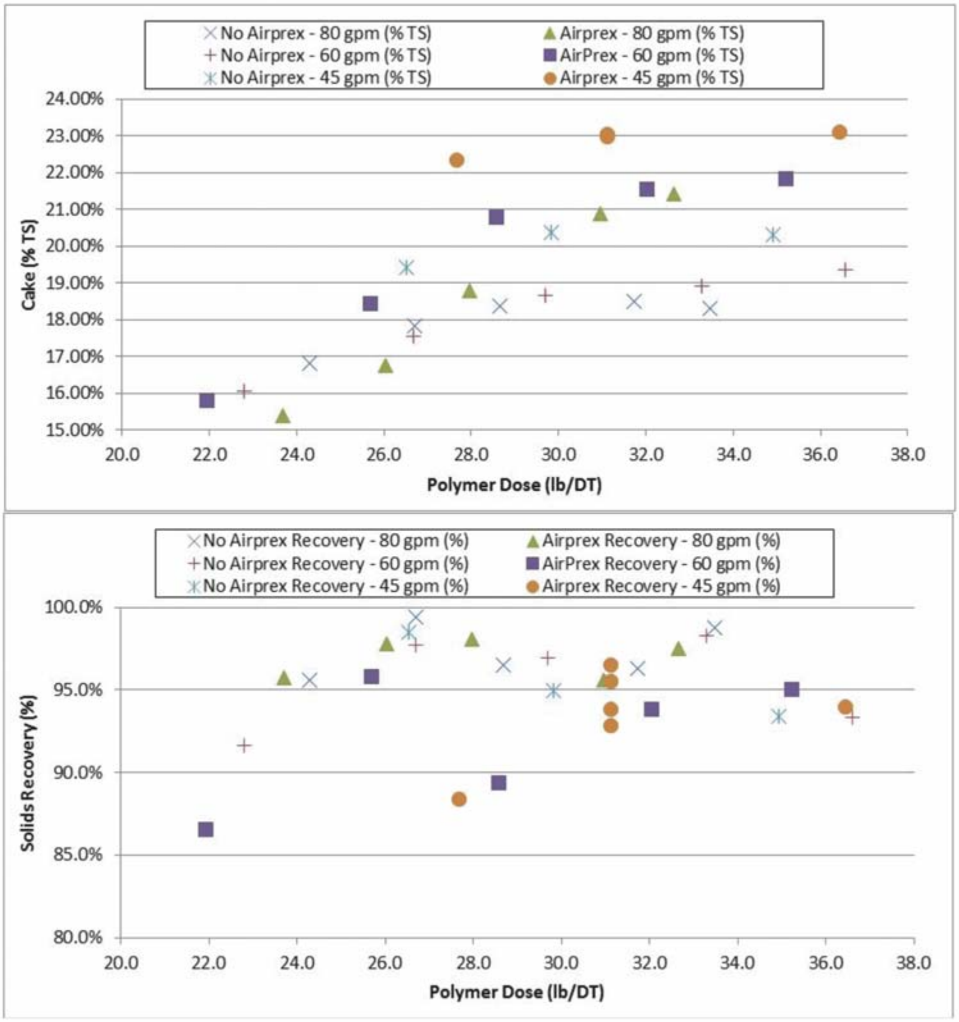

Figure 23. Summary of All Digester 10 Dry Polymer Curves With and Without AirPrex

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AirPrex and centrifuge pilot dewatering tests were conducted using the digested biosolids from Digester 10.

Dry Polymer Curve Testing

In order to better gauge the impact that the AirPrex treatment had on the dewaterability of the digested biosolids from Digester 10, several dry polymer curve tests were conducted at 45, 60, and 80 gpm, with and without AirPrex pretreatment. The flow rate, feed concentrations, dry polymer concentration, and dates for these tests are summarized in Table 3. For all of the tests the bowl speed was maintained at 93 percent, which is equal to 3,100 rpm.

All of the dry polymer curves conducted with and without AirPrex on the digested biosolids from Digester 10 are summarized in Figure 23. The data for all three polymer curves show that, with AirPrex pretreatment, the sludge dewatering was improved, allowing close to a 3 percent increase in the dry solids content at the same polymer dosing rate. The data also show that the driest cake achievable without AirPrex pretreatment can be achieved with AirPrex pretreatment at a lower polymer dose. When comparing the trends with and without AirPrex, however, it can be seen that, without AirPrex, the optimal polymer dose, meaning the point where additional polymer dose does not improve cake solids, is lower. Table 4 summarizes

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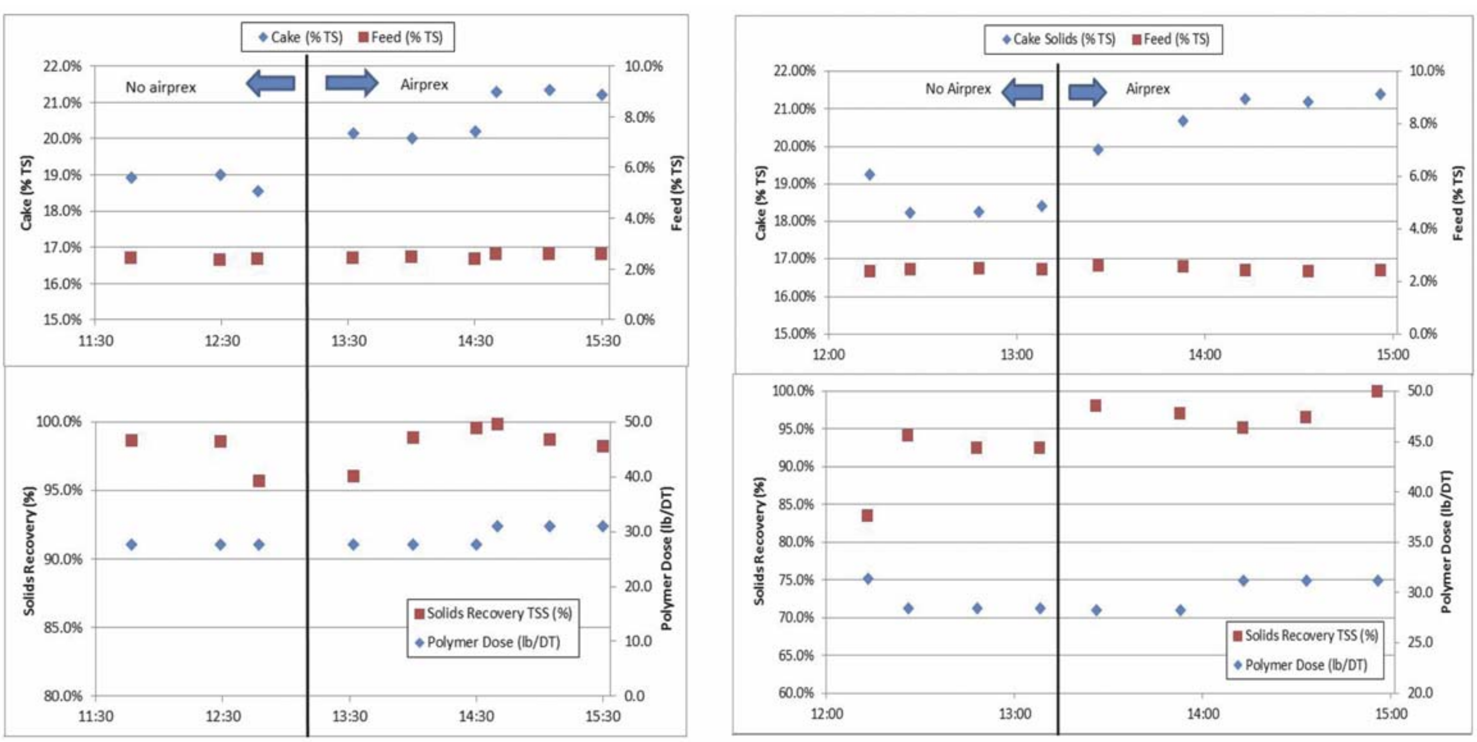

Figure 24. Centrifuge Operation With Dry Polymerat 60 gpm, April 14, 2016 (right), and at 80 gpm, April 15, 2016 (left)

Continued from page 46

the optimal point based on the polymer curves with and without AirPrex treatment.

The data show that, with lower throughputs, lower differential speeds can be maintained and dryer cake can be produced with AirPrex treatment, compared to operation without AirPrex treatment. The results also indicated that, with AirPrex treatment, up to 21 to 23 percent TS cake could be achieved, with recoveries at or above 93 percent when a 30 to 32 lb/DT active polymer dosage rate was used. This is compared to operation without AirPrex, showing that 18 to 20 percent TS cake can be achieved with recoveries at or above 95 percent when a 29 to 30 lb/DT active polymer dosage rate was used.

Extended Operation Testing

In order to test the stability of dewatering operation for the AirPrex-treated digested biosolids, several extended operation tests were conducted at 45, 60, and 80 gpm using digested biosolids from Digester 10. For all of the tests, the bowl speed was maintained at 93 percent (3,100 rpm) and polymer concentrations were approximately 0.4 percent TS. With the tests conducted at 60 and 80 gpm, the testing started with an extended run on non-AirPrex-treated biosolids based on the optimal settings and then switched to AirPrex-treated biosolids to see the impact over the course of the run.

On April 14, 2016, an extended operation test was conducted at 60 gpm, targeting the optimal setting from Table 4, and the results are summarized in Figure 24. When running on the non-AirPrex-treated biosolids, with a differential speed of 3.3 rpm and a polymer dose of 27.6 lb/DT active, the centrifuge dewatered the biosolids from approximately 2.4 to 18.9 percent TS, with a solids recovery of 97.7 percent. When the centrifuge feed was switched to AirPrex-treated biosolids at the same polymer dose (27.6 lb/DT active), but with a lower differential speed of 2.5 rpm, the dewatered cake solids increased to 20.1 percent TS (starting with a 2.5 percent TS feed) and recoveries were maintained at 98.2 percent. Further increasing the polymer dose to 31 lb/DT active improved the dewatered cake solids to 21.3 percent TS, and recoveries were near 100 percent. Because of the high recovery, the differential was further reduced to 2.3 rpm, but this did not show improvement in dewatering, and recoveries were still at 98.5 percent. During the run on April 14, 2016, the non-AirPrex-treated feed averaged 2.4 percent TS and the AirPrex-treated feed averaged 2.5 percent TS; the polymer concentration averaged 0.42 percent TS. The results, based on the optimal setting, matched the results indicated by the previously conducted polymer curve, shown in Figure 23.

On April 15, 2016, an extended operation test was conducted at 80 gpm, and the results are summarized in Figure 24. The test again targeted the optimized setting outlined in Table 4, but the testing was further expanded to gauge the impacts on the differential speed and polymer dose on dewaterability. The test started with non-AirPrex-treated biosolids using the optimized differential speed settings (3.1 rpm) and polymer dose settings (31.4 lb/DT) for the AirPrex-treated biosolids. At these settings, up to 19.3 percent TS cake was produced, but recovery was only 83.6 percent. When the differential was increased to 4.2 rpm and the polymer dose was reduced to 28.4 lb/DT, the dewatering was reduced to 18.3 percent TS, but recoveries improved to

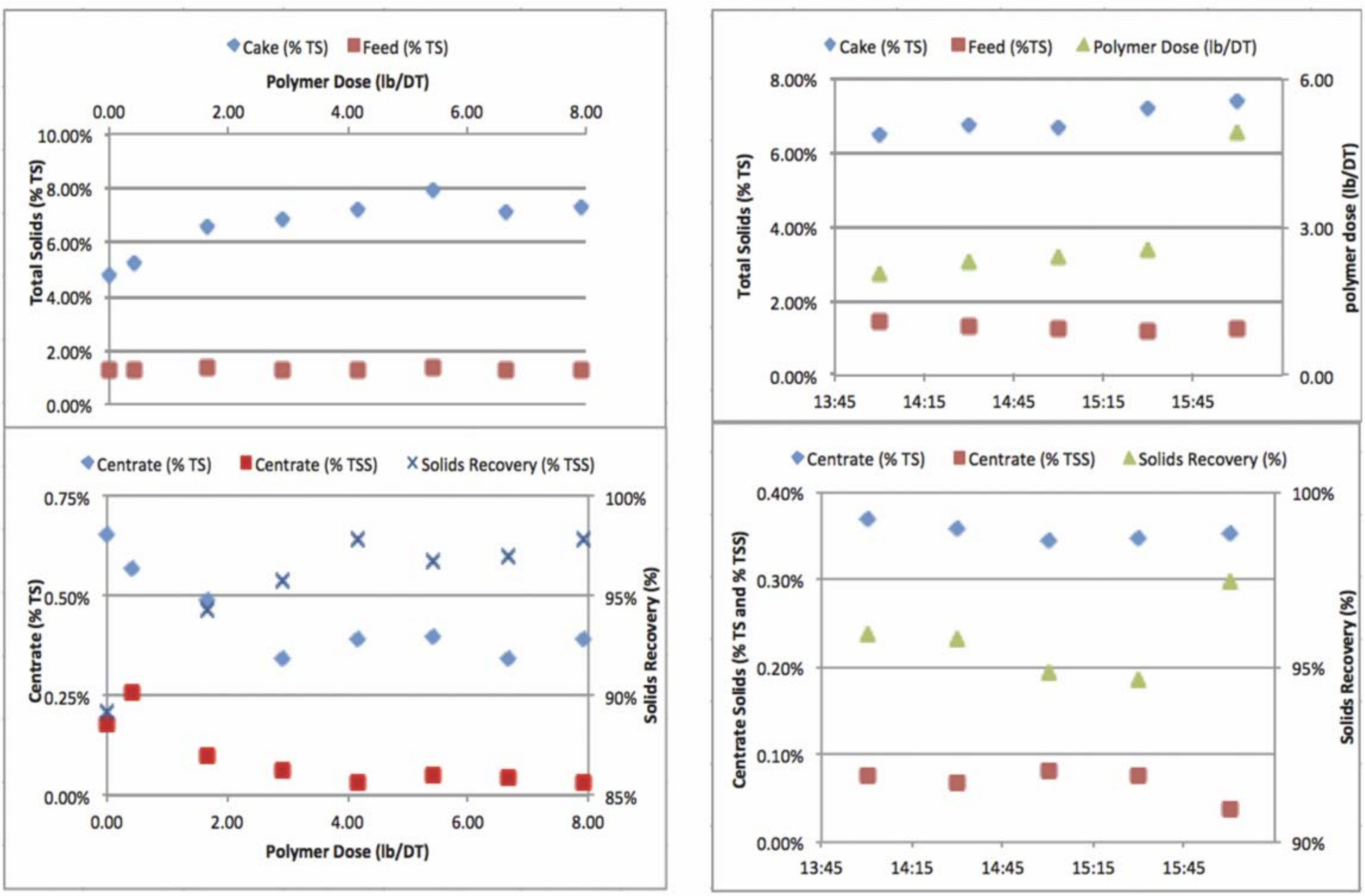

Figure 25. Dry Polymer Curve and Extended Operation Data, Central District Wastewater Treatment Plant, Waste Activated Sludge Only

93 percent. When switching to the AirPrex-treated biosolids, without adjusting any of the centrifuge parameters, the dewatered cake solids improved to 19.9 percent TS and recoveries improved to 98.1 percent. Lowering the differential to 3.2 rpm with the same polymer dose increased the dewatered cake solids to 20.7 percent TS, and recoveries were still high at 97.1 percent.

Finally, when adjusting the differential speed and polymer to the optimized AirPrex setting outlined in Table 4 (3.1 rpm and 31.2 lb/DT active), the dewatered cake solids improved to 21.3 percent TS, with recoveries of 97.3 percent, showing slightly better results than indicated by the previously conducted polymer curve (Figure 23). Throughout the testing, the feed biosolids concentration (both with and without AirPrex treatment) averaged 2.5 percent TS and the polymer concentration averaged 0.43 percent TS.

On April 16, 2016, an extended operation test was conducted at 45 gpm right after conducting the 45-gpm polymer dose test with AirPrex-treated sludge. The testing showed that, when operating at a 1.5 rpm differential speed and an active polymer dose of 31.1 lb/DT, dewatering up to 23 percent TS, with recoveries at 95 percent, were possible. The marginal increase in differential speed allowed the recoveries to improve to 95 percent, compared to operation at 1.4 rpm differential speed. The feed solids concentration during this run averaged 2.4 percent TS and the polymer concentration averaged 0.44 percent TS.

Central District Wastewater Treatment Plant Phase 1: Thickening Pilot Testing

Thickening Pilot Setup

Thickening in the pilot unit was tested without polymer, with emulsion polymer, and with dry polymer. The pilot unit was set up to allow injection of polymer at two locations, as illustrated in Figure 5, either directly into the bowl of the unit (internal injection) or in the sludge feed line upstream of the centrifuge inlet (external injection). Polymer flow was measured during each sampling event using a calibration column located on the pilot trailer.

The emulsion polymer used for testing was PRAESTOL K144-L, a cationic, high-molecular-weight emulsion polymer. Two different dry polymers were also tested, including the dry polymer currently used in the CDWWTP gravity concentrators (SNF Polydyne Clarifloc SE-1138) and dry polymer currently used in the CDWWTP dewatering centrifuges (SNF Polydyne Clarifloc SE-1141).

Figure 26. Central District Wastewater Treatment Plant Lakeside Raptor Screens for North District Wastewater Treatment Plant Sludge

Thickening Pilot Testing: Central District Wastewater Treatment Plant Waste Activated Sludge

For the CDWWTP WAS-only thickening operation, the system was set up and operated with emulsion polymer, dry polymer, and without polymer. Polymer curve tests were conducted by maintaining a constant volumetric throughput of sludge feed to the centrifuge, while changing the polymer dose. With the exception of changing the polymer dose, all other parameters on the centrifuge remained the same for each polymer curve test. After generating the polymer curves, the unit was operated several days at a constant flow rate, with optimized settings to test the stability of operation throughout the course of a day.

The testing showed that the centrifuge, operating on CDWWTP WAS only, could reliably thicken the WAS from 0.9 to 1.3 percent TS to 5 to 6 percent TS, and achieve greater than 95 percent solids recovery. Testing was conducted using both dry and emulsion polymers. The dry polymer required 3 to 4 lb/DT active dosing compared to 0.6 to 3 lb/DT based on the emulsion. It was also possible to thicken the sludge to 5 to 6 percent TS without the use of polymer, but this reduced hydraulic throughput by about 25 percent to allow solids recoveries to remain above 95 percent. Examples of polymer curve data and extended operation data collected are provided in Figure 25 (Stitt et al., 2018).

Thickening Pilot Testing: North District Wastewater Treatment Plant Primary and Waste Activated Sludge

When the pilot operation initially began in May 2016, the 6-mi, 16-in. line from the interceptor that allowed NDWWTP sludge to be fed to CDWWTP gravity thickeners was out of service, so pilot testing of NDWWTP sludge could not begin until this was brought back in service. In addition, the amount of debris and grit in the sludge from NDWWTP, which have historically been problematic for CDWWTP operations, was exacerbated during the piloting period, since the primary sludge degritters at NDWWTP were out of service for a replacement.

In order to provide a solution to minimize the impact of rags and grit for an interim period before the consent decree projects were to be implemented, MDWASD operations installed two Lakeside Raptor® screens, shown in Figure 26 on the receiving pipe for NDWWTP sludge. The unit contains a screening system and an aerated grit chamber that provides removal of both rags and grit to a dumpster.

The NDWWTP sludge from the screens was directed to one of the CDWWTP gravity concentrators.

Testing of the NDWWTP sludge started at the end of June 2016 and testing ultimately continued through mid-September 2016. During the testing period, daily plant records for NDWWTP sludge production and transfer operations were provided to the PMCM team, which included information of flow to Force Main #1 and the solids concentration. The preliminary design for NDWWTP sludge concentration was 0.75 percent TS average, with a range from 0.5 to 1 percent TS, but data collected showed that the NDWWTP concentration was typically less than 0.5 percent TS.

Initial testing was conducted mostly on NDWWTP primary sludge since a large proportion of the WAS was directed to Force Main #2 to the influent of CDWWTP due to limitation in the piping. On Aug. 29, 2016, after some piping modifications were made, all NDWWTP sludge began going through Force Main #1, and this mode of operation remained throughout the duration of the pilot, which concluded on Sept. 15, 2016. The combination of thin sludge

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Figure 27. Central District Wastewater Treatment Plant and North District Wastewater Treatment Plant Blend Tank

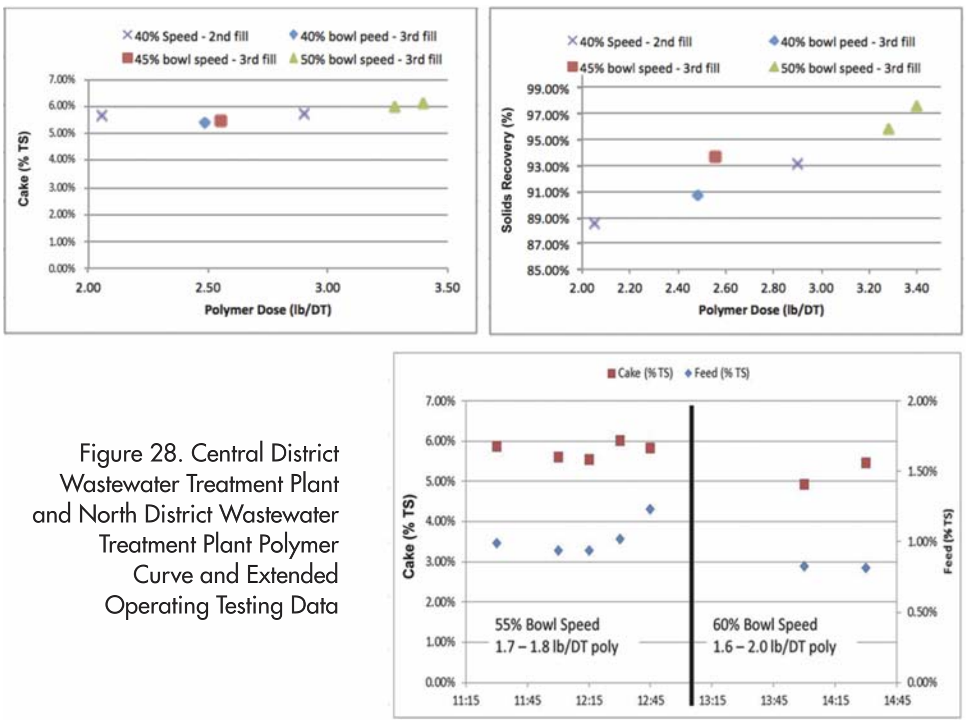

Figure 28. Central District Wastewater Treatment Plant and North District Wastewater Treatment Plant Polymer Curve and Extended Operating Testing Data

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and the high proportion of primary sludge made thickening in the pilot centrifuge very difficult.

Although the CDWWTP WAS-only sludge was easily able to thicken in the pilot centrifuge, NDWWTP primary sludge and WAS, which was more dilute, was difficult to handle and thicken reliably. After testing NDWWTP primary sludge and WAS alone, using multiple parameters, a stable operation could not be maintained. Initial attempts to blend NDWWTP primary and WAS with CDWWTP WAS, using an in-pipe blending system, were also unsuccessful.

Because of the difficulties with NDWWTP primary and WAS operation, a separate frac tank and recirculation pump were rented to allow a buffer for NDWWTP primary and WAS and for better control of blending CDWWTP WAS and also NDWWTP primary and WAS. When NDWWTP sludge was blended with CDWWTP sludge in the blend tank, shown in Figure 27, stable operation could be maintained in the centrifuge, and greater than 5.5 percent TS-thickened sludge with greater than 95 percent solids recovery could be achieved. The dry polymer required 1.5 to 3 lb/DT active dosing compared to 2 to 3 lb/DT, based on the emulsion. The testing showed that including a blend tank to mix CDWWTP and NDWWTP sludge would be important for future operation to be successful. Example data collected for thickening CDWWTP and NDWWTP sludge blend are provided in Figure 28.

The setup used during the pilot, however, had several limitations with regard to capacity, tank mixing, and flow metering that should not be issues in a full-scale system. Because of the limitations, there were some variations noted for day-to-day operation. In addition, during the time of testing, the feed pump on the pilot centrifuge was wearing out and close to failure due to excessive wear on the stator from grit. Because of these issues, it was not possible to con-

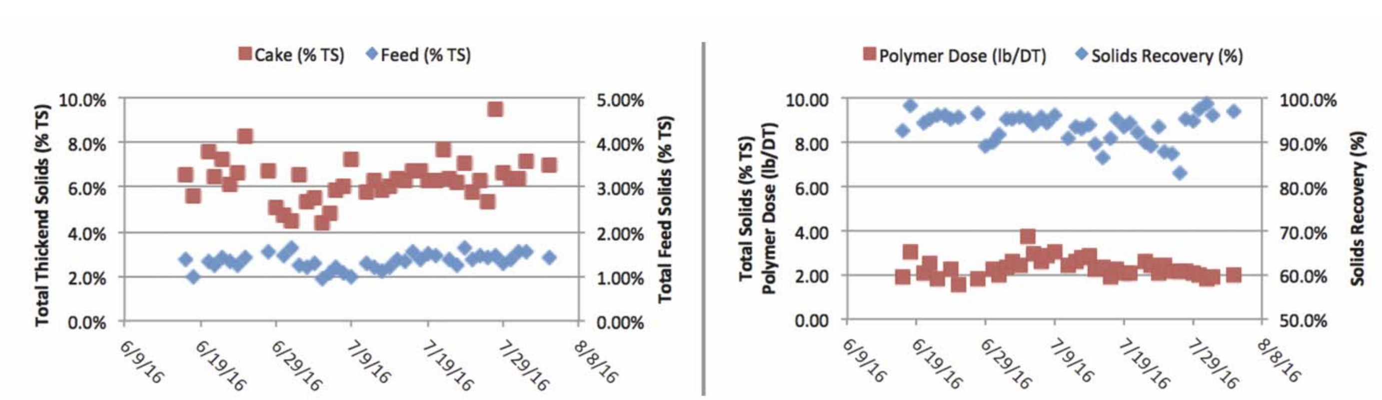

Figure 29. Continuous Thickening Operation

duct an extended operation run for more than two to three hours at a time.

Central District Wastewater Treatment Plant Phase 2: Continuous Thickening Pilot Operation

Centrifuge-thickened sludge was fed to Plant 2, Cluster 1, and Digester 3 (the test digester) to simulate future high-rate single-stage mesophilic anaerobic digestion conditions and to increase the solids content of the digested biosolids for the dewatering pilot operations. Near-continuous operation began in mid-June and the team maintained continuous operation through mid-August, but performance testing on CDWWTP and/or NDWWTP sludge continued to be conducted during normal workday hours, with operation switching to CDWWTP WAS only for overnight and weekend operations. A manifold was set up to allow switching between NDWWTP and CDWWTP sludges and was also used initially to blend the sludges. Mechanical problems with the unit, specifically the thickened cake pump, limited the throughput and the operation time. The stator in the thickened sludge pump had to be replaced several times throughout the duration of the pilot.

For the stable period (shown in Figure 29), the thickened solids content to the digester averaged 6.3 percent TS (with a 2.3 lb/DT active polymer dose) and the VS content of the raw sludge being fed to the digester averaged 86 percent VS/TS. The solids content in the test digester was increased to approximately 2.8 to 3 percent TS. For comparison, the rest of the digesters operating at CDWWTP were being fed gravity-thickened sludge at approximately 3.8 percent TS with a VS content of 83 percent VS/TS, and the other operational digesters operated at an average of 2.2 percent TS. The VSR estimations during this period ranged from 50 to greater than 70 percent, while the digester was approaching a steady state.

Central District Wastewater Treatment Plant Phase 3: Dewatering Pilot Testing

The purpose of the dewatering pilot operation was to determine the optimal design conditions and performance of the dewatering centrifuge using the thickened biosolids fed from the test digester. The overall target for the centrifuge dewatering performance, as stated in the basis of design and specifications, was to dewater the thickened digested biosolids to greater than 24 percent TS, while maintaining greater than 95 percent solids recovery. The necessary

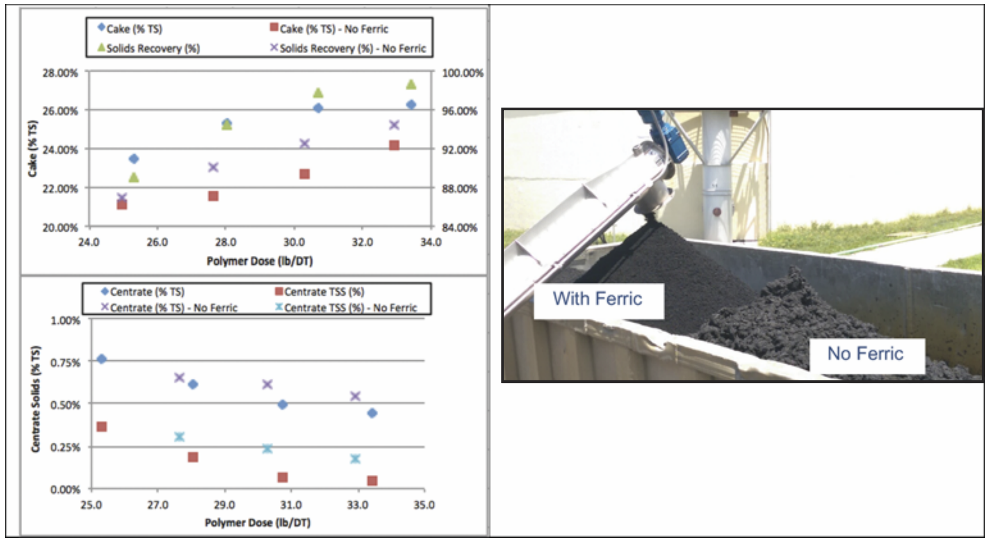

Figure 30. Central District Wastewater Treatment Plant Dewatering Polymer Curve Testing With and Without Ferric (data, left; photo of cake, right)

polymer dose to achieve this performance is also important to determine.

The draft specifications indicate that the active polymer dose should be less than 25 lb/DT. The M&E fifth edition (2013) lists 22 to 25 percent TS expected for anaerobically digested WAS and primary sludge, with the polymer consumption expected to be 15 to 30 lb/DT active polymer dose and solids recoveries expected to be 95 percent or greater. The CDWWTP currently doses ferric sulfate at a rate of 1.9 gal per 1000 gal of sludge ahead of the centrifuges for struvite control. This practice is planned to continue in the future, so a temporary ferric dosing system was also included with the pilot.

Dewatering Pilot Testing: Setup

For the dewatering pilot, the system was set up and tested with emulsion and dry polymer, as well as ferric sulfate conditioning, similar to the current CDWWTP dewatering operation. The majority of the testing was conducted using the plant's dry polymer, which is more representative of the future design; however, some limited testing was also conducted using emulsion polymer to provide a comparison.

The initial dewatering operation was dedicated to optimizing the machine for the site-specific operation. Adjustable parameters included the pool depth, bowl speed, and differential scroll speed. The pool depth was adjusted manually through adjustment of the outlet weir plate and throughout all of the dewatering operation, and the system was operated with the B weir plate, which corresponds to the second deepest pool depth. For most of the dewatering operation, the centrifuge also operated at the highest bowl speed of 3,350 rpm. It was also found that injecting polymer directly into the feed tube was the best injection point, compared to other polymer injection locations tested.

Initial testing started with emulation polymers on Aug. 11, 2016. Three cationic, high-molecular-weight emulsion polymers were tested in order to determine the top polymer type for further testing. The emulsion polymers were able to achieve 21 to 26 percent TS with greater than 95 percent solids recovery, but required higher polymer doses than listed in the specifications (>30 lb/DT). Since the emulsion polymer dosing requirements were high compared to the specification requirements and the basis of design is for a dry polymer, only limited further testing was conducted using emulsion polymer.

The dry polymer used for all of the dewatering testing was Polydyne Clarifloc C-SE-1141, which is currently used for CDWWTP dewatering centrifuges. This dry polymer testing used for the duration of the pilot was optimized to start performance testing on Aug. 17, 2016.

Dewatering Pilot Testing: Polymer Curve Testing

Polymer curve tests were conducted by maintaining a constant volumetric throughput of digested biosolids feed to the centrifuge, while changing the polymer dose to measure the impact. With the exception of changing polymer dose, most of the other parameters on the centrifuge remained the same for each polymer curve test.

Polymer curve tests were conducted pri-

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marily on dry polymer with feed tube polymer injection. Testing was mostly done with ferric sulfate dosing, but testing without dosing ferric sulfate was also done as a comparison. The data for this comparison are shown in Figure 30. The cake solids ranged from 23.5 to 26.3 percent TS, with the addition of ferric sulfate. Without the addition of ferric sulfate, the cake solids were 3 to 4 percentage points lower, ranging from 21 to 24 percent TS. The difference in solid content was visibly noticeable, as can be seen in Figure 30. Without the addition of ferric sulfate, the solids recovery was also noticeably worse than operating with ferric sulfate.

Dewatering Pilot Testing: Extended Operation Results

In addition to polymer curve tests, the dewatering centrifuge was operated for two days at a constant flow rate to test the stability of operation throughout the course of a day. Two tests were conducted at 80 gpm using dry polymer. Throughout the course of the test, it was desired to maintain constant settings; however, periodic adjustments were made based on visual observations of both the dewatered solids concentration and the centrate quality. The pilot field staff collected samples during these trials approximately once every 30 minutes to one hour, depending on the total duration of the particular test.

One extended run using dry polymer is shown in Figure 31. Performance during this run was stable, with dewatered cake solids averaging 25 percent TS and solids recoveries averaging over 98 percent for all samples collected. The feed during this run was consistent, averaging 3 percent TS. The differential speed was held at 3 rpm during the five hours of operation. The power consumption averaged about 0.19 kilowatt (kW)/gpm. The polymer concentration during this run averaged 0.8 percent and the active polymer dose averaged 25.8 lb/DT.

The results of the dewatering piloting indicate that the centrifuge dewatering unit will be able to achieve a total cake solids of >24 percent TS and solids recovery requirements of >95 percent. The testing showed that >24 percent TS cake could be achieved with 25 lb/DT active dosing of dry polymer and a ferric sulfate dose equal to 1.9 gal ferric sulfate per 1,000 gal of sludge. Testing conducted without the use of ferric sulfate conditioning showed that dewatering performance was reduced by 2 to 4 percent TS in cake solids and that the solids recovery percentages were lower. The centrifuge could achieve 26 to 28 percent TS with emulsion polymer, but the polymer dosages are higher and almost double that of the desired maximum of 25 lb/DT active.

Conclusions

Throughout the pilot studies at SDWWTP and CDWWTP, two plants with identical treatment processes, the results clearly show how site-specific sludge conditions drive the thickening and dewatering process performance, and pilot testing for the design of sludge thickening and dewater is a crucial step in properly designing and setting plant expectations.

The SDWWTP Phase 1 thickening testing showed that the centrifuge could reliably produce solids at 5 to 6 percent TS and achieve greater than 95 percent solids recovery. Testing was conducted using both dry and emulsion polymers. The dry polymer required 5 to 7 lb/DT active dosing compared to 1 to 3 lb/DT, based on the emulsion. It was also possible to thicken the sludge to 5 to 6 percent TS without the use of polymer, but this reduced hydraulic throughput by about 50 percent to allow the solids recovery to remain above 90 percent.

During SDWWTP Phase 2, the solids content in Digester 9 was increased from approximately 2 percent to approximately 3.4 to 3.5 percent TS, and the VSR in Digester 9 averaged 46 percent with a digester SRT of approximately 30 days. During the same period of time, the other digesters at the plant received gravity-concentrated sludge at 1.5 to 3 percent TS, and averaged approximately 42 percent VSR, with a digester SRT of approximately 20 days. The increase in VSR was likely due to the longer SRT and higher solids concentration.

The SDWWTP Phase 3 dewatering testing showed that 16 to 18 percent TS cake could be achieved with 20 to 30 lb/DT active dosing of dry polymer. The pilot testing showed that the dewatered cake solids were lower than the preliminary design value of 20 percent TS, with a presumed 25 lb/DT active polymer when using dry polymer without sludge pretreatment. Dryer cake at 20 to 22 percent TS could be produced using emulsion polymer, but required higher dosages above 40 lb/DT active.

It was found that removal of orthophosphate through struvite recovery within the digestion process resulted in a two- to four-point increase in the cake solids in the downstream dewatering process, compared to operation without struvite recovery and similar active polymer dosages. The conclusion of the pilot determined that, to achieve a greater than 20 percent cake solids (up to 22 percent cake solids, in fact) was achieved with AirPrex pretreatment, as compared to 19 percent without pretreatment, using 25 to 35 lb/DT active polymer dosages.

The CDWWTP Phase 1 WAS-only thickening testing showed that the centrifuge, operating on CDWWTP WAS only, could reliably produce solids at 5 to 6 percent TS and achieve greater than 95 percent solids recovery. Testing was conducted using both dry and emulsion polymers. The dry polymer required 3 to 4 lb/DT active dosing compared to 0.6 to 3 lb/DT, based on the emulsion. It was also possible to thicken the sludge to 5 to 6 percent TS without the use of polymer, but this reduced hydraulic throughput by about 25 percent to allow solids recoveries to remain above 95 percent.

Although the CDWWTP WAS-only sludge was easily able to thicken in the pilot centrifuge, NDWWTP primary sludge and WAS, which was more dilute, was difficult to handle. After testing the NDWWTP primary sludge and WAS alone, stable operation could not be maintained. Initial attempts to blend NDWWTP primary and WAS with CDWWTP WAS using an in-pipe blending system were also unsuccessful.

Because of the difficulties with NDWWTP primary and WAS operation, a separate tank was rented to allow a buffer for NDWWTP primary and WAS, and for better control of blending CDWWTP WAS, and NDWWTP primary and WAS. When NDWWTP sludge was blended with CDWWTP sludge in the blend tank, stable operation could be maintained in the centrifuge and greater than 95 percent solids recovery was achieved. The dry polymer required 1.5 to 3 lb/DT active dosing compared to 2 to 3 lb/DT, based on the emulsion. The testing showed that including a blend tank to mix CDWWTP and NDWWTP sludge is important for future operations to be successful.

The near-continuous operation of CDWWTP Phase 2 began in mid-June and the team maintained continuous operation through mid-August, but mechanical problems with the unit, specifically the thickened cake pump, limited the throughput and the operation time. For the stable period, the thickened solids content to the digester averaged 6.3 percent TS (with a 2.3 lb/DT active polymer dose) and the VS content of the raw sludge being fed to the digester averaged 86 percent VS/TS. The solids content in the test digester was increased to approximately 2.8 to 3 percent TS. For comparison, the rest of the digesters operating at CDWWTP were being fed gravity-thickened sludge at about 3.8 percent TS, with a VS content of 83 percent VS/TS, and the other operational digesters operated at an average of 2.2 percent TS. The VSR estimations during this

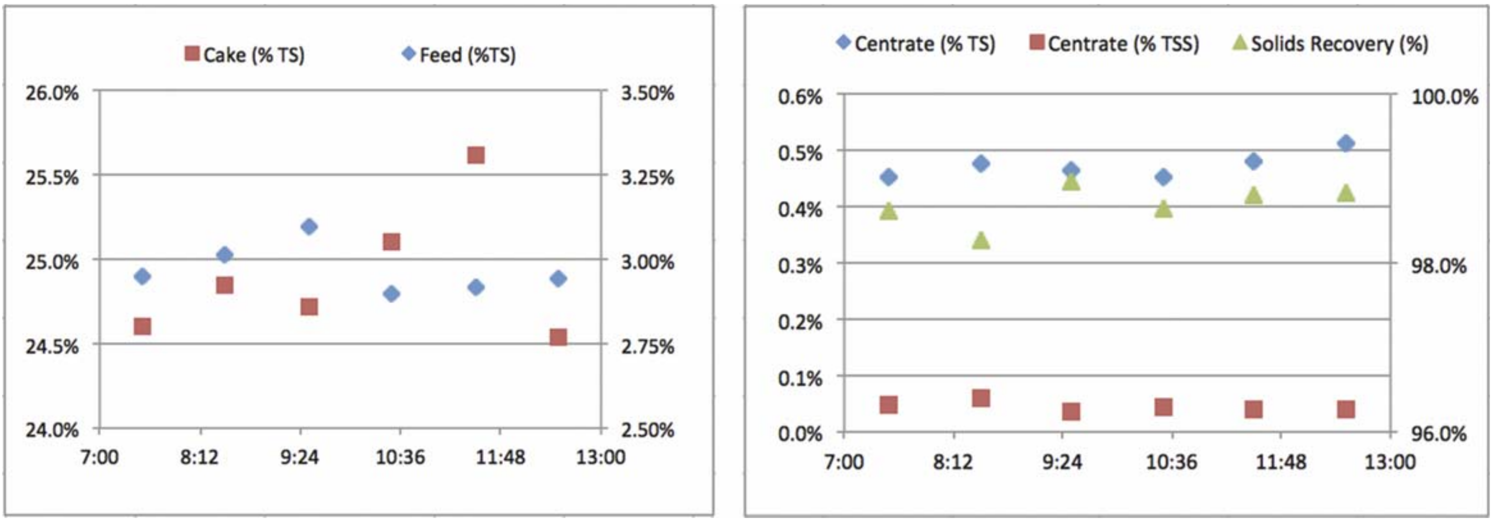

Figure 31. Extended Operation Using Dry Polymer

period ranged from 50 to greater than 70 percent, while the digester was approaching a steady state.

The results of the CDWWTP Phase 3 dewatering piloting indicate that the centrifuge dewatering unit will be able to achieve total cake solids of >24 percent TS and solids recovery requirements of >95 percent. The testing showed that >24 percent TS cake could be achieved, with 25 lb/DT active dosing of dry polymer and a ferric sulfate dose equal to 1.9 gal ferric sulfate per 1,000 gal of sludge. Testing conducted without the use of ferric sulfate conditioning showed that the dewatering performance was reduced by 2 to 4 percent TS in cake solids and that solids recovery percentages were lower. The centrifuge could achieve 26 to 28 percent TS with emulsion polymer, but the polymer dosages are higher and almost double that of the desired maximum of 25 lb/DT active.

Overall, the pilot testing was used to set the necessary performance criteria for a design-build package. The CDWWTP testing also showed the importance of including a blend tank to be able to successfully manage and thicken the highly variable sludge quality from the primary, and WAS from NDWWTP. The dewatering portion of this pilot at SDWWTP accentuated the importance of properly identifying possible dewatering challenges, namely the impact of high struvite potential, and that to achieve the performance goals, extra considerations may need to be added to the design. The pilot results as a whole highlight the importance of piloting to determine operational difficulties and to refine design performance criteria.

Acknowledgments

The team would like to thank all of the plant staff at SDWWTP and CDWWTP, especially Leo Pou, Francois Saint-Phard, Mike Garcia, and David Hall for their outstanding support during this pilot testing. The team would also like to thank the staff from Centrisys and CNP Corp. for their commitment to making the testing a success. We also thank the interns Gabriela Aramayo, Alejandro Cepero, Andres McEwen, and Yareliz Negron, from Florida International University, and Kate Ireland, from University of Miami, who helped make this project possible by monitoring pilot operations, collecting samples, and running numerous laboratory tests.

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