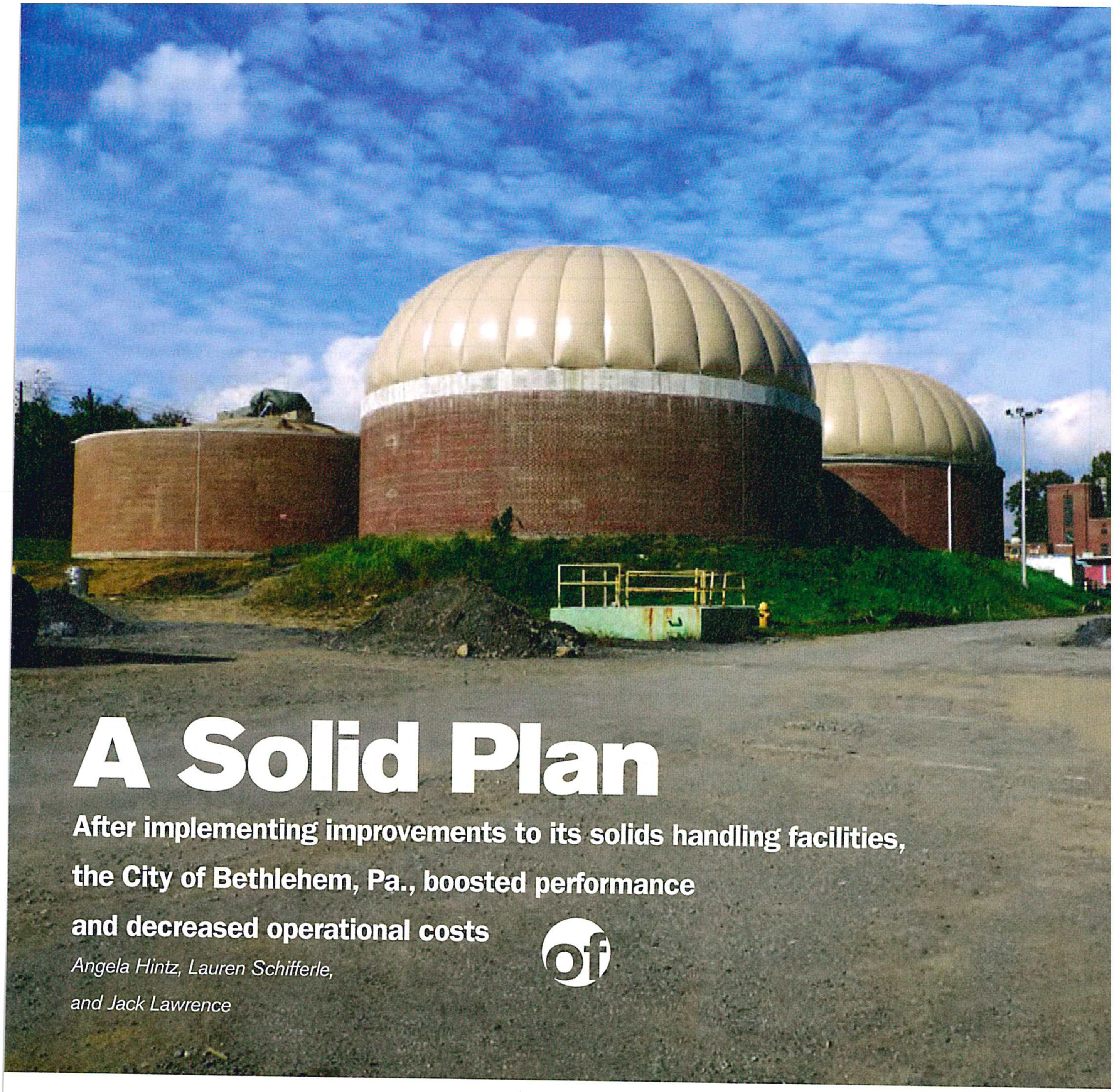


A Solid Plan

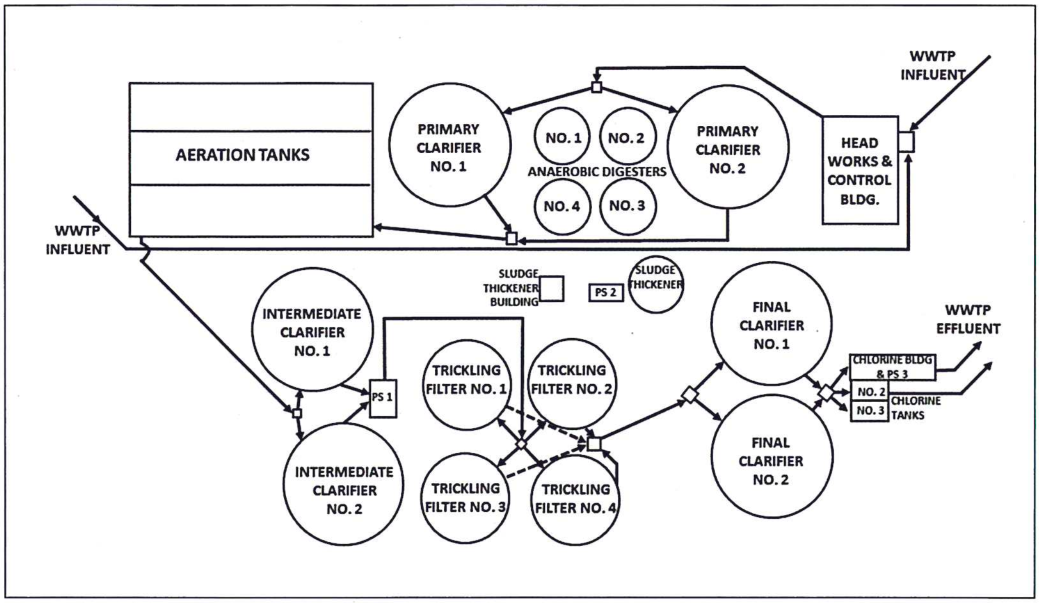
After implementing improvements to its solids handling facilities, the City of Bethlehem, Pa., boosted performance and decreased operational costs

Angela Hintz, Lauren Schifferle, and Jack Lawrence

When making improvements to its 75,700-m^3/d (20-mgd) water resource recovery facility (WRRF), the City of Bethlehem, Pa., historically has focused on wet stream treatment processes, mainly to comply with combined sewer overflow regulations. However, in preparing a planning document required by the Commonwealth of Pennsylvania, the city and its consultant – Arcadis US Inc. (Highland Ranch, Colo.) – identified several potential changes that could be made to the facility's processes involving solids thickening, anaerobic digestion, and dewatering. In recent years, the city has phased in several of the recommended upgrades to the solids handling processes, significantly improving performance, reducing operational costs, and realizing opportunities for additional savings.

In 2008, Arcadis completed for the city an update of a planning document known as an Act 537 Plan, named after the pertinent Pennsylvania code requiring the development of the document for any upgrades or replacements to wastewater collection, conveyance, and treatment infrastructure. The updated Act 537 Plan noted the poor performance of, and absence of operational flexibility within, the solids handling processes at Bethlehem's WRRF. These drawbacks adversely affected the performance of the wet stream treatment processes and generated insufficient levels of biogas, forcing the city to spend extra money to buy supplemental fuel to heat the digesters. To correct these deficiencies, the plan identified a host of potential improvements to the facility's solids thickening, anaerobic digestion, and dewatering processes.

Figure 1. Wet stream treatment process schematic



belt filter presses. Belt conveyors discharged dewatered cake from the belt filter presses to a nearby offloading facility, from where the cake was hauled to a local landfill for disposal. Figure 2 (below) depicts the solids handling treatment process.

Evaluation of the solids handling data during the development of the Act 537 Plan revealed suboptimal performance on the part of the solids handling treatment processes. In some cases, the processes performed significantly poorer than those of other, similar facilities. Table 1 (p. 62) shows the average daily performance of the solids handling processes at the treatment facility in the mid-2000s.

Inadequate solids treatment

At Bethlehem's WRRF, the wet stream treatment process comprises influent bar screens, mechanical grit-removal systems, two primary clarifiers, a conventional plugflow aeration tank with mechanical surface aerators, two intermediate clarifiers, intermediate pumping, four rock-media-polishing trickling filters, two final clarifiers, and chlorine disinfection. (See Figure 1, above.) Treated effluent is discharged to the Lehigh River.

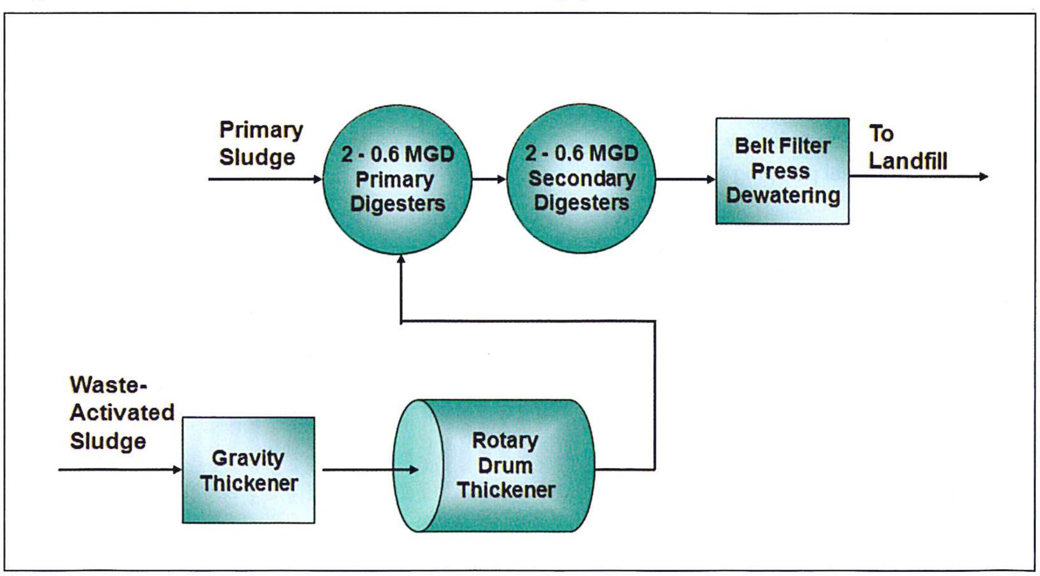
At the time of the update to the Act 537 Plan, primary sludge was collected in the primary clarifiers and pumped directly to the primary anaerobic digesters. Waste activated sludge (WAS) from the intermediate clarifiers was drawn from the return activated sludge line by a sludge pump, which conveyed WAS to the gravity thickener for "pre-thickening." Gravity-thickened WAS then was discharged to the rotary drum thickener. Thickened WAS from the rotary drum thickener was discharged through a chute to an adjacent thickener pit. Two submersible pumps in the thickener pit further conveyed the thickened WAS to the primary digesters.

As primary sludge and thickened WAS were pumped into the two primary digesters, an equal amount of digested material was displaced to the two secondary digesters for storage. Digested material from the secondary digesters flowed by gravity to the suction of the filter press feed pumps. Three pumps fed the two

Addressing the thickening problems

As noted earlier, primary sludge was not thickened before undergoing digestion. However, WAS underwent thickening twice, first through a gravity thickener and then through a rotary drum thickener, before being sent to the digesters. Even so, the resulting thickened WAS only achieved approximately 3.5% solids concentrations before digestion. According to commonly used design guidance, such as the *Manual of Practice No. 8 (MOP-8), Design of Municipal Wastewater Treatment Plants* – which is published by the Water Environment Federation (Alexandria, Va.) – gravity thickeners for activated sludge should be able to obtain solids concentrations of 2% to 3%. The subsequent rotary drum thickener should be able to achieve solids concentrations of 5.5% to 6%.

Figure 2. Schematic of initial solids handling process



Because both the gravity thickener and the rotary drum thickener were underloaded, the poor performance did not result from hydraulic or solids overloading. An evaluation of the facility data suggested that the poorer-than-expected performance for WAS thickening resulted from conditions within the activated sludge system, such as low dissolved oxygen concentrations that affected settleability in the intermediate clarifiers and in subsequent solids treatment processes.

The updated Act 537 Plan recommended the following improvements for the thickening processes:

- construction of a new 10.7-m- (35-ft-) gravity sludge thickener to thicken sludge before anaerobic digestion,
- continued prethickening of WAS in the existing gravity thickener, and
- replacement of the existing rotary drum thickener with two new gravity belt thickeners.

In June 2009, Bethlehem began using a temporary gravity belt thickener to replace the failing rotary drum thickener. In July 2013, the city began operating the two new gravity belt thickeners, which could achieve higher solids concentrations in the thickened WAS and reduce the hydraulic loading on the primary digesters. As part of this project, the city also installed new discharge pumps capable of pumping the more concentrated WAS to the digesters. Ultimately, the city decided not to proceed with the recommendation to construct a new primary-sludge thickener.

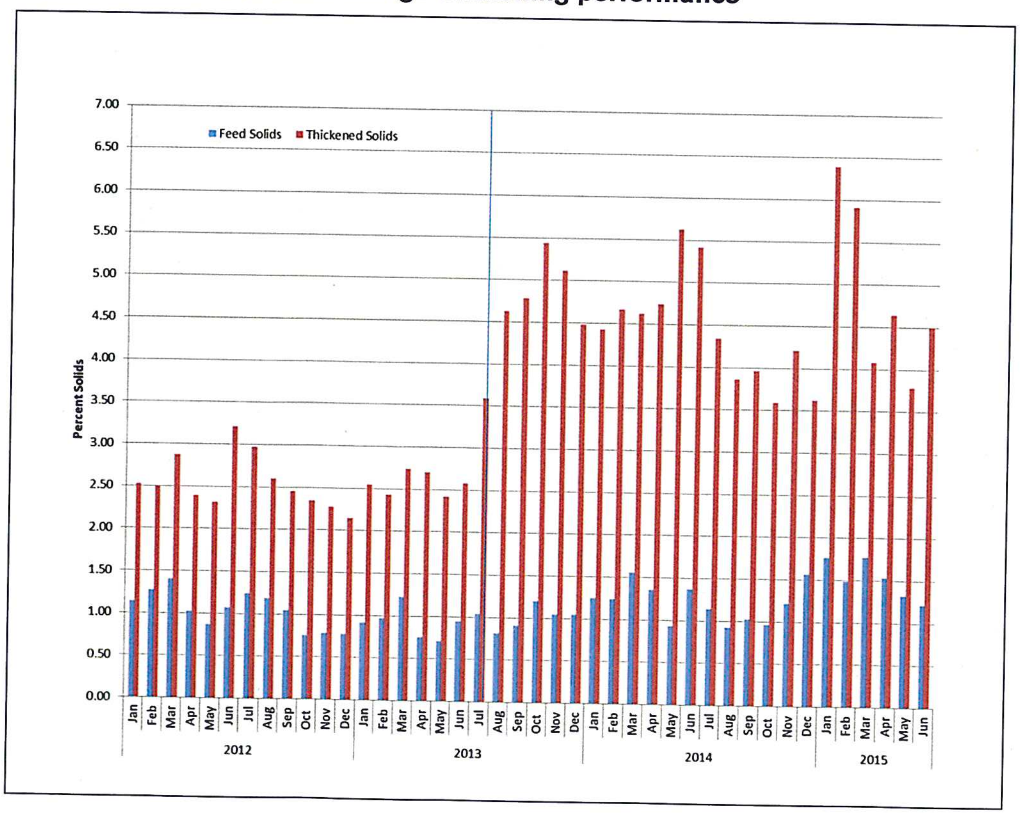
Thickening of WAS improved drastically. The new gravity belt thickeners and pumping capability essentially doubled the thickened solids concentration previously achieved with the rotary drum thickener. (See Figure 3, below.) At the same time, the volume of thickened WAS sent to the digesters also decreased accordingly. The average solids concentration of thickened WAS averaged 2.5% in 2012 and the first part of 2013. The use of the new gravity belt thickeners increased the thickened WAS concentrations to an average of 4.65% from August 2013 through mid-2015. Despite achieving thickened solids concentrations in excess of 6%, the staff has learned to maintain the thickness of the solids to below 5% to ensure optimal pumping efficiencies.

The major advantage of the improved WAS thickening performance was its effect on digester detention time. Following the improvements to the thickening processes, the average digester detention time increased from 13 to 14.5 days, with two primary digesters in operation.

Table 1. Solids handling process before improvements

Primary solids	
Volume	170 m³/d (45,000 gal/d)
% Solids	3.4%
Waste activated sludge (WAS)	
Volume	2,271 m³/d (600,000 gal/d)
% Solids	0.38%
Gravity-thickened WAS	
Volume	908 m³/d (240,000 gal/d)
% Solids	0.9%
Rotary-drum-thickened WAS	
Volume	170 m³/d (45,000 gal/d)
% Solids	3.53%
Digester influent	
Volume	340 m³/d (90,000 gal/d)
% Solids	3.4%
Digester effluent (47% volatiles destruction)	
Volume	340 m³/d (90,000 gal/d)
% Solids	1.84%
Belt filter press cake (5 days per week dewatering operation)	
% Solids	11.5%
Dry tons/day	8.14 Mg (8.97 tons)
Wet tons/day	70.76 Mg (78 tons)

Figure 3. Waste activated sludge thickening performance



New mixing and heating systems were installed within the two existing primary digesters, helping to improve homogeneity within the solids treated by the digesters and reduce grit settlement. Rainbow Photographic Documentation Co.

Dissecting the digester deficiencies

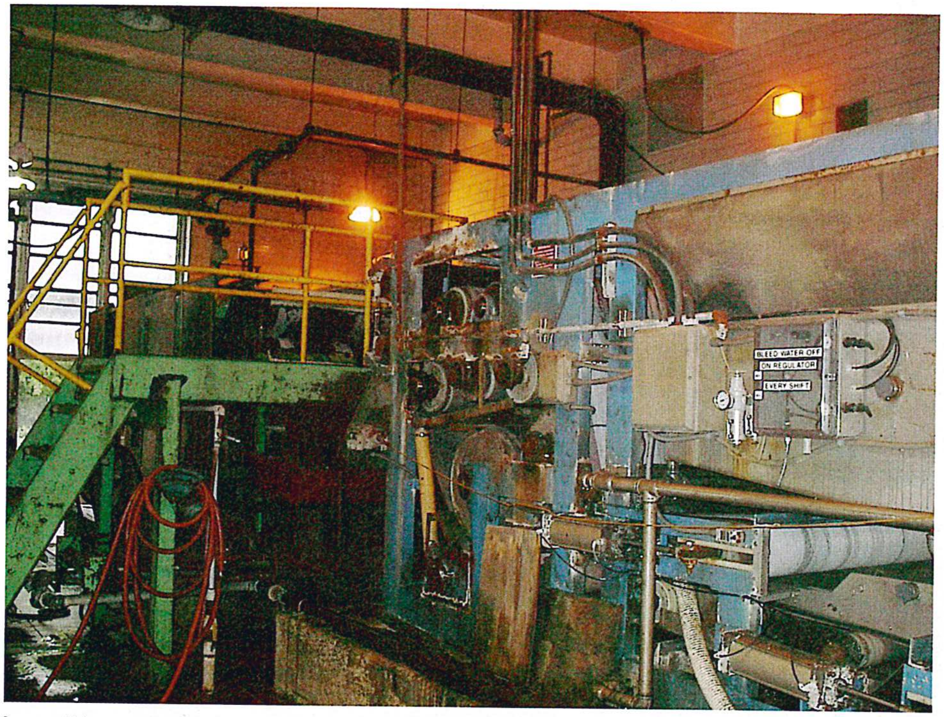
As noted in the updated 537 Act Plan, the digestion process also was experiencing problems, most notably achieving approximately 36% to 47% volatiles reduction in the two heated, primary digesters and two unheated, secondary digesters. Several causes contributed to the poorer-than-projected digester performance:

- ***Temperatures.*** The primary digesters were operating at temperatures around 29.4°C to 32.2°C (85°F to 90°F), which are lower than typical operating temperatures for mesophilic digesters.
- ***Mixing.*** The primary digesters were poorly mixed. The old gas-mixing system had completely failed, and the solids-recirculation pumps did not work effectively.
- ***Return streams from the solids handling processes.*** Solids from the final clarifiers and the rotary drum filtrate were returned to the head of the facility, collected as part of the primary sludge, and conveyed back through the digesters.
- ***High solids loading rate on the digesters.*** The volatile solids loading rate for the primary digesters was approximately 2.33 kg VSS/m^3·d (145 lb VSS/1000 ft^3·d). This loading is high for a moderately mixed system, which suggests a volatile solids loading rate of approximately 0.65 to 1.30 kg VSS/m^3·d (40 to 80 lb VSS/1000 ft^3·d) is more appropriate.
- ***Low retention times.*** With both primary digesters in service, the average retention time was approximately 13 days. Coupled with the lower operating temperatures and poor mixing, the existing digestion volume did not provide sufficient retention time for effective volatile solids removal.
- ***Low dewatering capture rates.*** Low solids capture rates of approximately 76% in the belt filter presses resulted in the recycling of digested solids back to the head of the facility. Ultimately, these solids returned to the digesters as part of the primary sludge.

As a result of these issues, the digesters did not produce enough biogas to heat themselves, forcing the city to purchase supplemental fuel.

To address these problems, the updated Act 537 Plan recommended the following improvements for the digestion process:

- Reroute the return flows from the solids handling processes – that is, belt press filtrate, thickener overflow, and gravity belt thickener filtrate – from the head of the plant to the head of the aeration tanks.
- Replace the existing heating and mixing systems with a new system for pumping, heating, and mixing solids in the two existing primary digesters.



Low solids-capture rates on the part of the existing belt filter presses resulted in the recycling of digested solids back to the head of the facility. Angela Hintz/Arcadis

- Convert, in phases, the two existing secondary digesters into primary digesters through the addition of a system for pumping, heating, and mixing solids. In the near-term, the city decided to convert only one secondary digester into a primary digester.
- Construct a fifth primary digester for ultimate future flows.

In August 2013, the city converted one secondary digester into a primary digester. Because its cover had been damaged and needed replacement, the south secondary digester was the first to undergo the conversion to a primary digester. One existing primary digester was upgraded, as recommended, and brought online approximately 8 months later. As part of the digester upgrades, biogas and solids piping were replaced, as necessary.

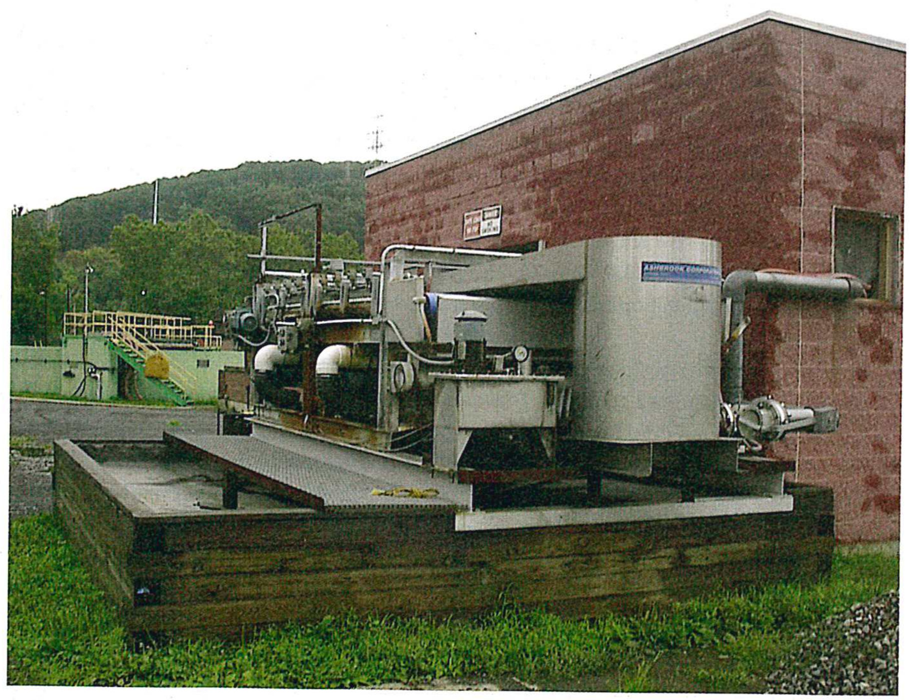
New mixing and heating systems were installed within the two existing primary digesters. This improvement, together with the addition of the third primary digester, will enable the digesters to reach and maintain optimal mesophilic operating temperatures of 35°C (95°F). The new mixing systems also are expected to improve homogeneity within the combined solids and reduce grit settlement, alleviating concerns regarding cleaning.

As expected, the new heating and mixing systems enabled the primary digesters to perform much better in terms of reducing volatile solids. Following the installation of the new systems, the primary digesters increased their percentage of average volatile solids destruction by 10%, from approximately 45% to roughly 55%. (See Figure 4, p. 65.)

Boosting biogas production and capture

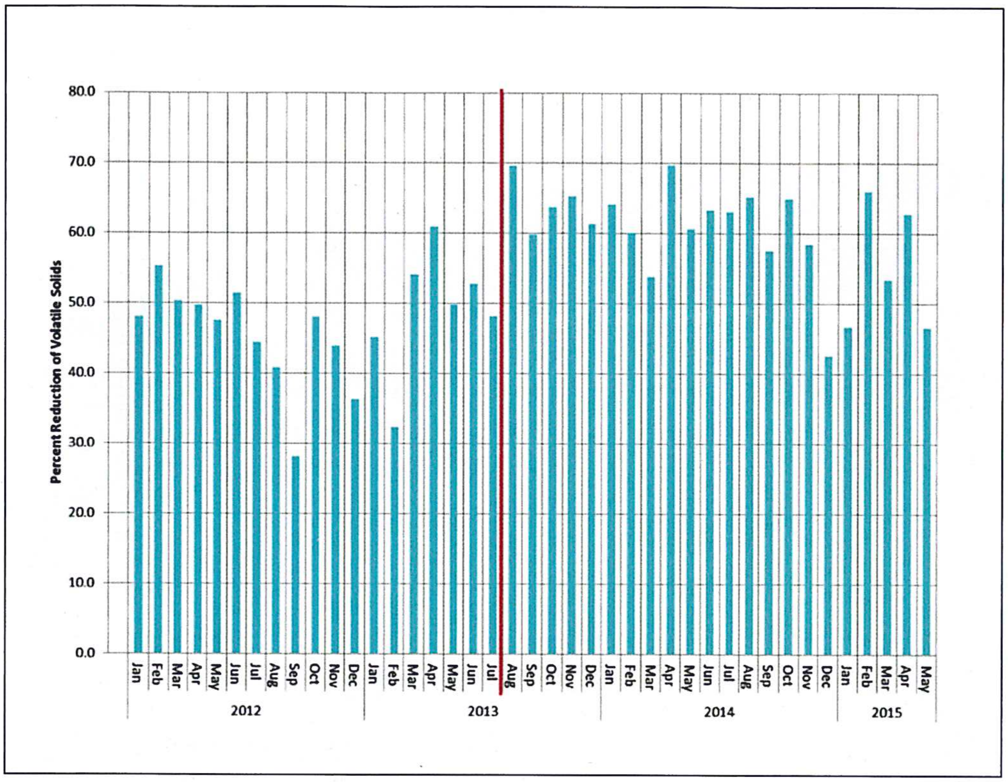
The improved performance of the upgraded primary digesters has led to increased biogas production. Biogas generation and capture increased from less than 2120 m^3/d (75,000 ft^3/d) before the upgrades, to more than 4250 m^3/d (150,000 ft^3/d) with the upgrade of the first digester. Upon completion of the improvements to the second primary digester, the volume of captured biogas increased even more, ranging from 4950 to 5670 m^3/d (175,000 to 200,000 ft^3/d).

Before the digester and thickening upgrades, the small amount of digester gas produced went mainly to the boilers used to heat the digesters, with a small amount of biogas wasted. (See Figure 5, p. 65.) With the significant increase in biogas generation, the city no longer has to purchase oil to supplement the biogas for digester heating. The city spent more than $78,000 for oil in 2011. Currently, the city spends less than $2000 annually on oil. In fact, current biogas production greatly outstrips onsite needs, raising the possibility of using biogas to generate electricity in a combined-heat-and-power system as part of a future project.



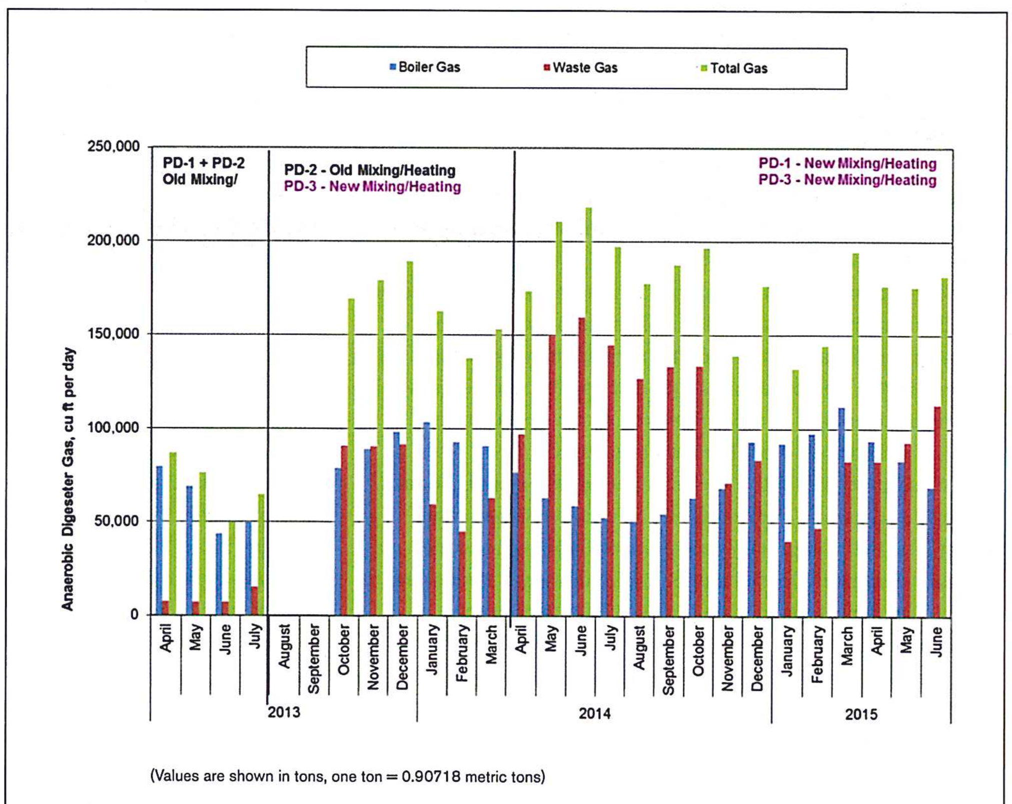
In June 2009, Bethlehem began using a temporary gravity belt thickener to replace the failing rotary drum thickener. Angela Hintz/Arcadis

Figure 4. Percent volatiles destruction in anaerobic digesters before and after digester upgrades



Preliminary calculations indicate that a single 350-kW engine generator would require 4900 m^3/d (172,800 ft^3/d) of digester gas at full load. This gas production has been achieved already with only two of the three primary digesters in operation. Heat exchangers would capture waste heat on the order of 47,400 kJ (45,000 Btu) per minute. This energy then would be used to heat the primary digesters and digester building. Besides enabling the city to save on supplemental fuel purchases, such a system would be able to generate an estimated 233,000 kilowatt-hours (kWh) of electricity per year. At 100% load, the generator output is 350 kW. Assuming a 90% run time, with 10% downtime for scheduled maintenance, the projected output of 230,000 kWh per month is approximately 35% of the total electrical energy use of the facility. This corresponds to a potential savings of $212,000 per year.

Figure 5. Biogas generation and use



Dewatering dilemma

In 2007, solids concentrations of the dewatered sludge cake averaged only 11.5%. In contrast, belt filter press installations at other facilities can produce cake solids in the range of 16% to 25% total solids, depending on the mixture of primary and secondary sludge. The low solids percent at the Bethlehem facility required the city to add additional material to the dewatered biosolids to achieve the minimum solids concentration of 20% that was required for landfilling.

Installed in the early 1980s, the two existing belt filter presses did not have sufficient capacity to allow for redundancy of operations. Both presses had to remain in service to maintain the solids inventory at acceptable levels and enable the facility to operate with low sludge blankets in the clarifiers. However, because of frequent mechanical and electrical issues, one or both belt filter

In July 2013, the city began operating two new gravity belt thickeners, which could achieve higher solids concentrations in the thickened waste activated sludge and reduce the hydraulic loading on the primary digesters. Rainbow Photographic Documentation Co. (Quakertown, Pa.)

presses were out of service periodically. In addition, because of limitations on the operating hours and maximum amount of solids allowed at the disposal landfill, dewatering operations typically were limited to 5 days per week, 16 hours per day.

During weekends, or when one or both filter presses were out of service, solids accumulated within other treatment processes, primarily in the digesters. If the secondary digesters lacked sufficient volume, excess solids were stored in the primary clarifiers and intermediate clarifiers by increasing sludge blanket levels. This practice resulted in septic conditions within the primary clarifiers and poor settling of the mixed liquor suspended solids in the intermediate clarifiers.

The updated Act 537 Plan recommended a mix of process changes and capital improvements to improve dewatering operations. Initial improvements primarily were operational in nature. For example, the city began operating a temporary dewatering centrifuge in June 2009 to supplement the performance of the aging belt filter presses until a more permanent dewatering solution could be designed and constructed. Ultimately, the updated plan called for replacing the existing belt filter presses with dewatering centrifuges and constructing a new 2300 m^3 (600,000 gal) solids storage tank upstream of the solids dewatering process.

Improving the WAS thickening and anaerobic digestion boosted the performance of the downstream dewatering process. The thickening improvements reduced the hydraulic load on the dewatering equipment, while the digester improvements reduced the solids load and improved the condition of the digested solids. Once the first upgraded primary digester became operational, the volume of solids to be dewatered decreased slightly. (See Figure 6, p. 67.) This decrease resulted from increased volatile solids reduction within the digesters.

The intermittent use of the temporary dewatering centrifuge also has provided a significant advantage. The centrifuge can produce a thicker cake than the belt filter presses while using approximately the same amount of polymer – 10 to 15 kg/dry Mg (20 to 30 lb/dry ton). On average, the centrifuge can produce a cake having a solids concentration 7.7% greater than that produced by the belt filter presses.

Since 2009, the belt filter presses and the centrifuge have been used to dewater digested biosolids, as neither process alone typically has the capacity to treat all the biosolids. The two different dewatering processes were able to achieve a combined sludge cake concentration of approximately 16.6% and varied typically between 10.7% (belt filter press

Table 2. Annual solids production and projections of future solids production

Year	Average dewatering feed solids concentration (%)	Average dewatered cake solids concentration (%)	Cake dry tons (Mg/d [ton/d])	Cake wet tons (Mg/d [ton/d])	Full year solids disposal * (wet Mg [wet tons])
2007	1.84%	11.50%	8.14 (8.97)	70.8 (78)	17,690 (19,500)
2011	1.67%	13.85%	7.48 (8.25)	54.74 (60.34)	13,685 (15,085)
2012	1.44%	17.22%	7.41 (8.17)	43.74 (48.21)	10,935 (12,054)
2013	1.63%	17.72%	7.33 (8.08)	41.93 (46.22)	10,482 (11,555)
2014	1.83%	17.83%	6.14 (6.80)	34.03 (37.51)	8508 (9378)
2015 (projected)	1.72%	15.59%	6.72 (7.41)	43.87 (48.36)	10,959 (12,091)
Future Years	1.72%	20.00%**	7.08 (7.80)	35.38 (39)	8845 (9750)

* Assumes dewatering takes place 250 days every year.

** Specifications for the permanent centrifuge installation require a minimum of 20% solids.

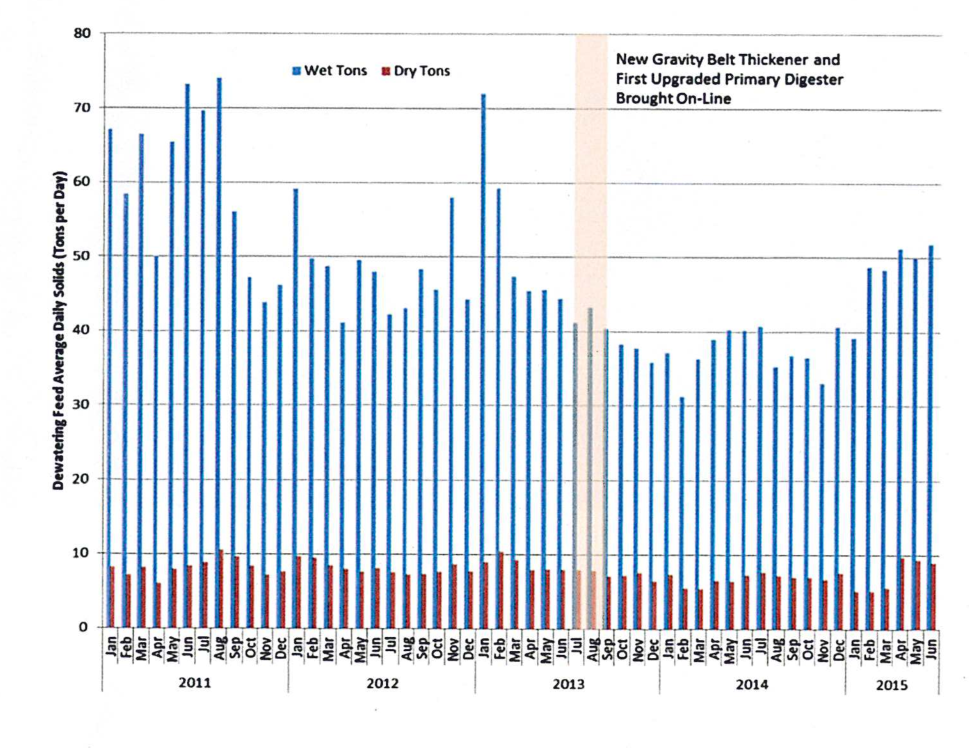
alone) to 19.8% (centrifuge alone). With the installation of new permanent centrifuges, it is expected that the treatment facility consistently will be able to achieve cake with a solids concentration of 17% to 20%, significantly decreasing the amount of cake. It is expected that the new centrifuges will be placed into operation in August 2016.

Solid savings

Table 2 (above) summarizes the historical quantities of dewatered biosolids and estimates the future sludge cake quantities to be produced. In 2007, the facility generated 17,700 wet Mg (19,500 wet tons) of sludge cake. Introduction of the centrifuge in 2009 greatly reduced the volume of cake. In 2013, the amount of dewatered biosolids dropped further because of the greater volatile solids reductions of the upgraded digesters. In future years, once the permanent centrifuges are installed, the treatment facility is expected to generate approximately 8860 wet Mg (9750 wet tons) annually, a reduction of more than 50% compared to 2007. As a result, the city can expect to save nearly $648,000 annually in costs associated with hauling and disposing of biosolids.

When combined with the savings resulting from the increased biogas production, the improvements to Bethlehem's solids handling treatment train are expected to save the city approximately $935,000 per year if the proposed combined-heat-and-power system is installed. The higher quality of solids produced with these improvements also benefits the city, as alternate disposal options, including land application, are now more viable and may offer additional cost savings in the future.

Figure 6. Quantities of dewatering-process feed solids



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