Lessons Learned From Start-Up of a Codigestion Process

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Broward County Water and Wastewater Services (utility) owns and operates the 95-mil-gal-per-day (mgd) North Regional Wastewater Treatment Plant (plant), located in Pompano Beach. Its liquids processing systems include preliminary treatment, secondary treatment through an activated sludge process, and disinfection. Waste activated sludge is thickened by dissolved air flotation and stabilized in a conventional anaerobic digestion process consisting of seven primary digesters and one secondary digester. Class B biosolids are dewatered by belt filter presses and dewatered cake is hauled to either land application sites or to landfills.

The plant utilizes 5.5 megawatts (MW) of electricity, making it one of the largest single-point electrical consumers in Broward County. Under efforts to reduce carbon emissions to 1997 levels by 2015, the utility adopted a climate action plan. As a part of the plan, it teamed with OpTerra Energy Services (formerly Chevron Energy Solutions) and its partners, including Hazen and Sawyer through a performance contracting approach, to implement a biogas-to-energy project using the digester gas waste product from the existing anaerobic digestion process. The project was aimed at reducing the plant's energy footprint and carbon emissions by using the flared biogas as a renewable fuel. Historically, approximately 25 percent of digester gas has been recovered for digester heating and the remaining 75 percent of digester gas production was flared to the atmosphere. The goal of this project was to harness the energy of the existing biogas production, as well as maximize biogas production to generate additional energy onsite.

Two major components of this project included installation of a new 2-megawatt (MW) engine generator for conversion of biogas to electricity and construction of a fats, oil, and grease (FOG) receiving station. The station was constructed to collect and introduce the additional feedstock to the digesters to enhance biogas production. This FOG material was formerly directed to the plant influent, resulting in increased aeration energy demands for the liquid stream and adverse operation and maintenance impacts, including accumulation of FOG within underground pipelines. Redirecting this waste to the anaerobic digesters for resource recovery reduces other energy demands at the plant by an additional 250 kilowatts.

As a result of this project, the biogas from anaerobic digestion at the plant is now used to generate power through an engine generator. Using the electricity generated and the waste heat produced from the engine generator is commonly referred to as cogeneration, or combined heat and power (CHP). The electricity generated, in addition to other savings, is used to offset purchased electricity, allowing these savings to be applied to fund the project. The CHP system utilizes the biogas produced from the existing anaerobic digesters for generation of energy. Hot water from the cogeneration system is beneficially reused to heat the digesters to maintain the necessary mesophilic conditions via new connections to existing hot water boilers and heat exchangers. This reduces the frequency with which the boilers need to operate, thereby reducing the plant's electrical demand.

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Fats, Oil, and Grease Facility Overview

The FOG receiving facility is designed for an average daily flow of up to 60,000 gal. The receiving operations are designed for five days per week, with an average of 15 to 16 deliveries per day. The process flow for the FOG facility is shown in Figure 1. As shown in the figure, the FOG received at the facility is unloaded from the trucks into the FOG receiving tank, which equalizes FOG volumes and dampens the load-to-load variations and strength, thereby providing a consistent FOG loading rate to the digestion process. The FOG from the receiving tank is then mixed with the digested sludge, which is recirculated from the digesters, to the blend tank at a 2.5:1 ratio (sludge/FOG). The sludge/FOG blend is sequentially dosed from the blend tank into each digester's feed line, with no more than 300 gal fed to each digester per cycle to prevent shock loading to the digesters. The sequential dosing cycle is continued until the preset FOG dosing targets for the day are reached.

The new FOG receiving station includes two truck unloading stations, a 165,000-gal stainless steel FOG receiving tank, FOG transfer pumping to an 18,500-gal blend tank, and dosing pumps, as shown in Figure 2.

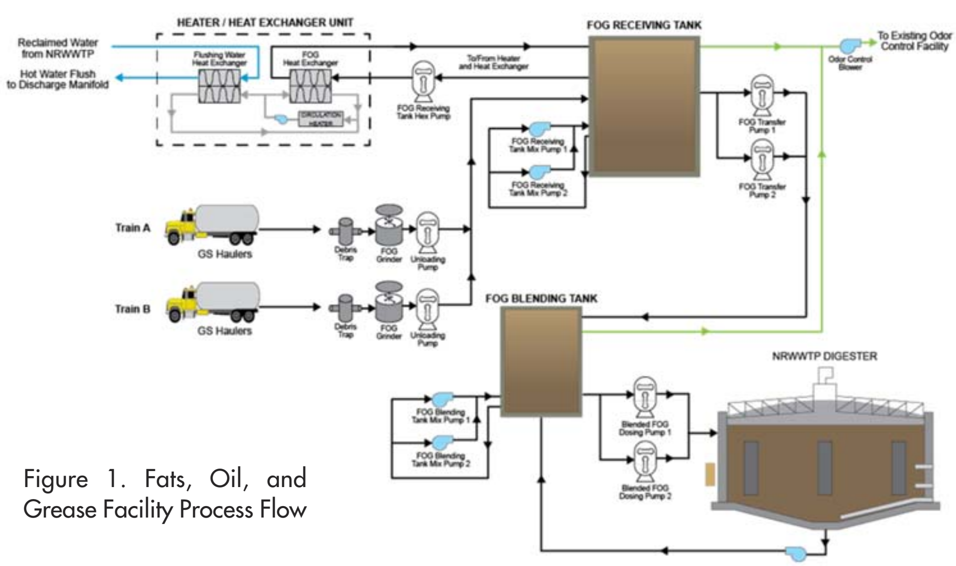

Figure 1. Fats, Oil, and Grease Facility Process Flow

Fats, Oil, and Grease Facility Start-Up and Operation

Start-up and commissioning activities for the FOG facility commenced in late December 2015. Functional testing of the facility was completed in March 2016, which was followed by the process start-up in April of that year. The facility has been in service since start-up, except for an approximately two-week period in mid-January when it was removed from service due to construction activities to increase the length of the unloading pads for the FOG receiving trucks.

Fats, Oil, and Grease Characteristics

The FOG samples are collected by the utility biweekly at a sample collection port on the transfer line between the FOG receiving tank and the blending tank. The location of the sample port enables collection of equalized samples that are representative of the FOG entering the solids stream. Overall, characteristics of the FOG received at the plant are highly variable, with the total solids (TS) ranging from 0.5 to 37 percent and total volatile solids (VS) ranging from 74 to 99 percent. The biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) ranges between 3,500 mg/L to 100,000 mg/L and between 6,900 and 150,000 mg/L, respectively. Additionally, the FOG received also contains plastics and debris in higher quantities than previously anticipated. Utility staff is working with haulers to reduce such waste, as it can damage the internal components of the system.

Fats, Oil, and Grease Dosing

Microorganisms within the anaerobic digesters require time to acclimate to the increased organic loading from high-strength wastes such as FOG or food wastes. Overdosing lipid-rich material can lead to accumulation of long-chain fatty acids, which in turn can cause a drop in pH, stress the microbes, and inhibit methane formation. Based on relatively limited industry experience, the "safe" limit for FOG dosing is generally considered to be 30 percent by weight of total VS in the digester feed. Recent research has demonstrated that if FOG dosing is increased slowly and gradually, digester microorganisms can adapt and support higher FOG loading, potentially increasing the ultimate "ceiling" and maximizing ultimate biogas production.

Since maximum sustained FOG dosing can exceed historically "safe" limits for codigestion, the initial FOG dosing during the start-up of the FOG facility was controlled in multiple steps, with each step increasing VS loading by no more than 5 percent. During the start-up phase, the utility implemented this step process, where FOG dosing was continuously increased, while allowing the di-

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Figure 2. Fats, Oil, and Grease Receiving Station at the North Regional Wastewater Treatment Plant

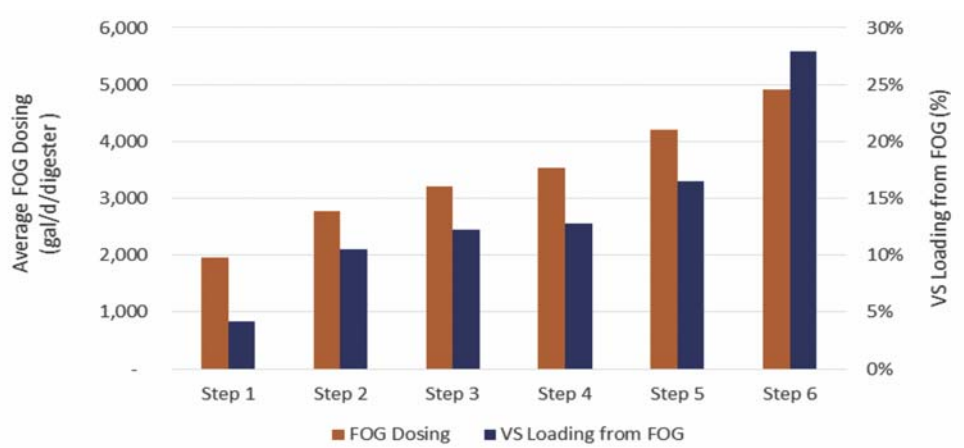

Figure 3. Fats, Oil, and Grease Dosing During Start-Up

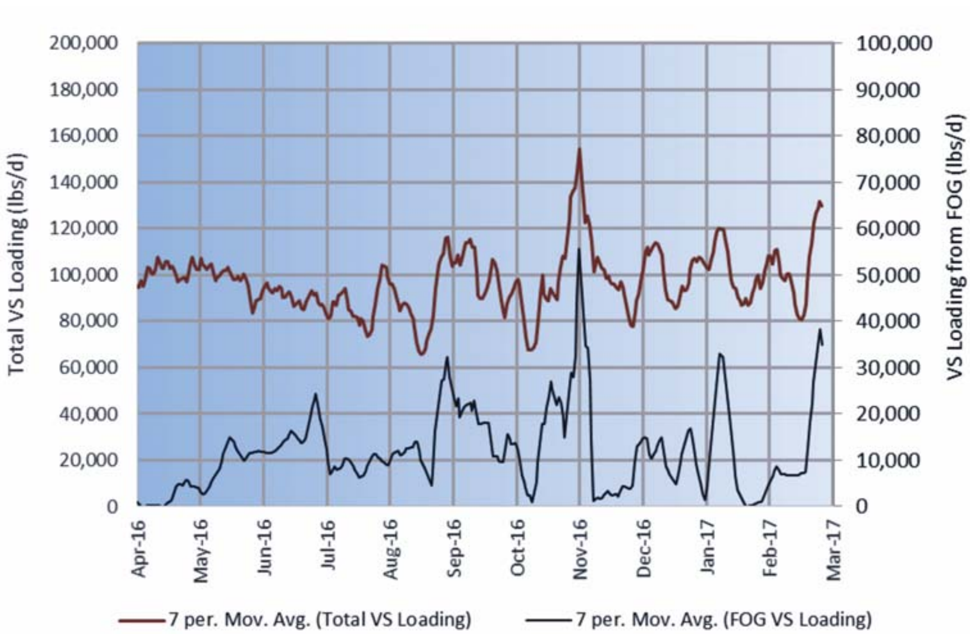

Figure 4. Volatile Solids to the Digesters Since Start-Up of the Fats, Oil, and Grease Facility

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gesters to acclimatize to the change in substrate and VS loading. Figure 3 illustrates the volumetric FOG dosing and the VS loading from FOG to the digesters during each step of the start-up phase. As shown in the figure, VS loading from FOG was gradually increased from approximately 4 to 28 percent throughout start-up. The FOG dosing was maintained constantly during each step, which lasted approximately one to two weeks.

Figure 4 shows the total VS loading to the digesters and VS loading from FOG following the start-up of the FOG facility in April 2016, which was completed in June 2016. The fluctuations in VS loading following the start-up were primarily due to variations in the supply of FOG trucks at the facility and high variability in characteristics of the FOG received. The low VS loading in early October was primarily due to very diluted FOG (total solids [TS] <1 percent) received at the facility, while the spike in VS loading in late November was primarily due to very high solids content in FOG (>19 percent). The FOG dosing was also reduced and subsequently halted in January 2017 due to construction activity onsite for expansion of the concrete pad for the FOG trucks. The pad expansion will accommodate larger FOG trucks with the intent of minimizing variations in FOG supply. Despite these variations in FOG feed, the digesters continued to perform well, which is likely due to acclimatization of the microbes in the digesters.

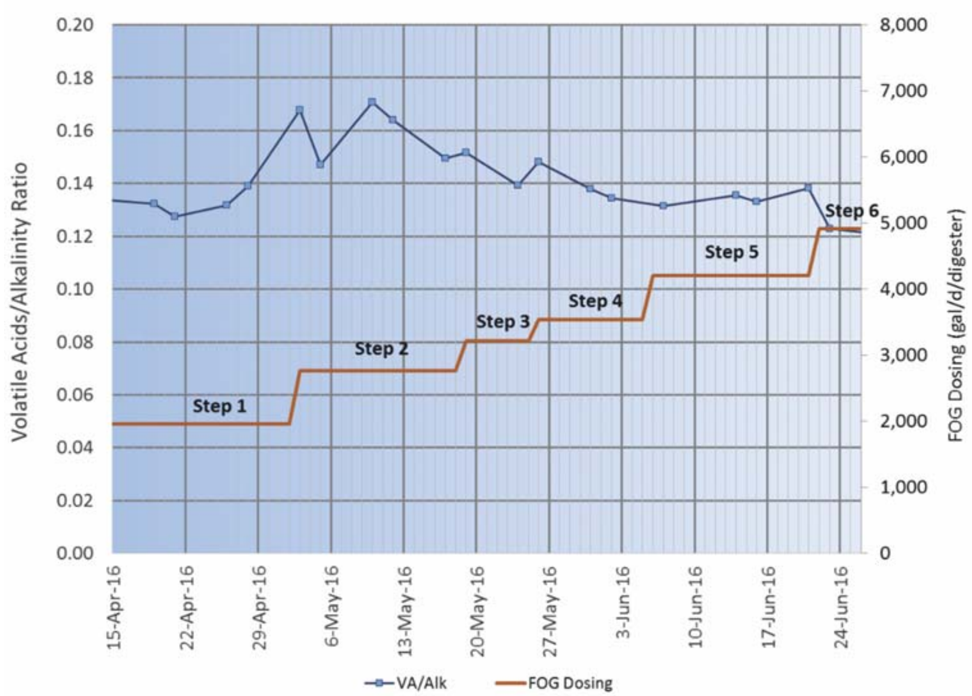

Figure 5. Volatile Acids/Alkalinity Ratio During Start-Up

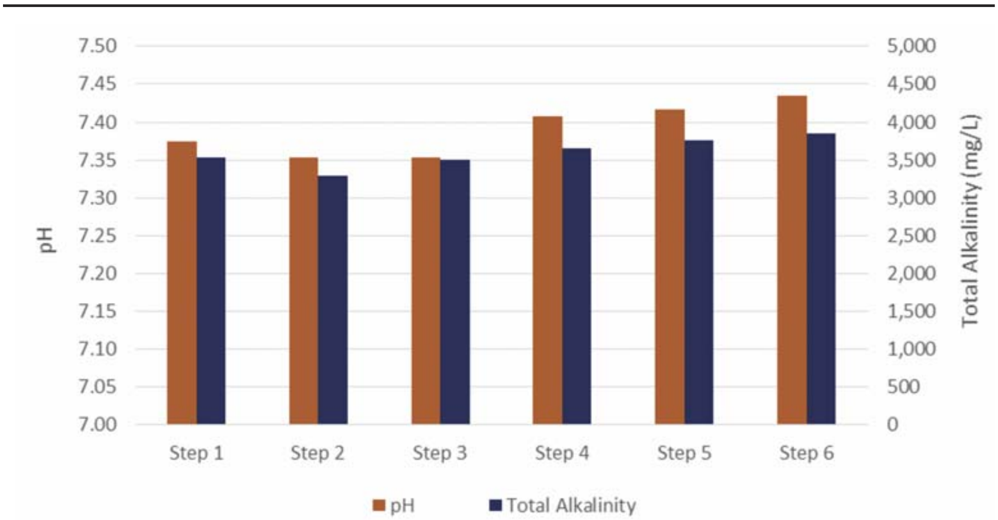

Figure 6. The pH and Total Alkalinity During Start-Up

Digester Performance

Digester performance was closely monitored and analyzed during the start-up of the FOG facility to preempt any digester upset conditions. Key codigestion process parameters monitored included:

- Thickened waste activate sludge (TWAS) loading (flow, total solids, and VS)
- FOG quantities (unloaded volume, TS, VS fraction, pH, COD, and BOD)
- FOG/digested sludge blend ratio and blended feed stock digester dosing rates
- FOG VS loading as percentage of total VS loading
- Individual digester liquid levels and hydraulic retention times
- Individual digester organic loading rates
- Individual digester volatile acids (VA), alkalinity, VA/alkalinity ratio, pH
- Digester gas production

Among several parameters analyzed for monitoring digester performance, the VA/alkalinity ratio was found to be most sensitive to fluctuations in VS loading to the digesters. With each increment in VS loading/FOG dosing during start-up, the VA/alkalinity ratio exhibited an instant spike, which stabilized over a period of one to two weeks. Figure 5 shows these variations in VA/alkalinity ratio with FOG dosing during the start-up. Despite the fluctuation, VA/alkalinity values were consistently less than the maximum recommended value of 0.35.

Additional digester performance indicators, such as pH and total alkalinity, remained relatively stable during the start-up phase (Figure 6). The pH in the digesters remained within 7 and 7.5 and the total alkalinity ranged between 3,300 mg/L and 3,800 mg/L. The decrease in total alkalinity when FOG dosing was increased from step 1 to step 2 is indicative of sensitivity of the digester to increase in FOG VS loading. The magnitude of increase in FOG VS loading was reduced in the subsequent steps to avoid "shock loading" the digesters.

Overall, the analysis of the digester parameters indicates that VA production did not exceed VA consumption and that the digesters had adequate buffering capacities to maintain suitable pH levels to avoid upset conditions.

Volatile Solids Reduction

One of the primary goals of the digestion process is volatile solids reduction (VSR). Due to the high FOG VS content, higher VSR is expected during codigestion, which in turn results in higher biogas production. The ability of the digesters to achieve higher VSR is contingent upon the capacity of digesters to handle high VS loading without going into "shock" (buildup of VA in the digesters), ultimately inhibiting the methanogenesis phase of the digestion process. As discussed previously, measures were taken to prevent "shock" loading of FOG to the digesters during the start-up by incrementing the FOG feed in steps. Digesters showed an increase in VSR, with an increase in FOG dosing during the start-up. The average VSR increased from 38 percent (July 2015 to December 2015) before FOG codigestion to 45 percent (April 2016 to Feb 2017) after start-up of the FOG codigestion process.

Biogas/Energy Production

The increase in VSR was accompanied by improvements in biogas production with an estimated increase of about 35 percent after FOG facility start-up, and monthly average electricity production ranged between 1 and 1.4 MW from the cogeneration/CHP system. Figure 7 shows the daily energy generated from the biogas produced. Due to the unavailability of direct biogas data, biogas production was estimated using the energy output of the cogeneration facility combined with the biogas utilized by the boilers for heating the digesters. Based on the available data, the average biogas production from the digesters is estimated to be approximately 35,000 cu ft per hour (ft^3/h) since the commencement of the cogeneration/CHP system in August 2016.

The monthly average biogas production per unit of VS destroyed ranged from 16 cu ft per pound (ft^3/lb) of VS destroyed to 23 ft^3/lb. This value is higher than the anticipated value of 15 ft^3/lb based on the literature review of similar systems.

Operational Considerations and Lessons Learned From Start-Up

The start-up of the FOG facility provided some useful lessons:

- The step-feed approach for FOG dosing during start-up allowed for the digesters to acclimatize to the change in substrate and VS loading and to achieve stabilization of the VA/alkalinity ratio.
- After initial start-up of the codigestion process, the digesters appear to be very resilient to variations in VS loading from FOG. This was particularly significant due to the variations in FOG supply and characteristics.
- Availability of FOG is an important consideration for successful operation of a FOG codigestion process. Several FOG suppliers also haul FOG comingled with septage (from portable toilets and septage facilities). Comingled loads are not accepted due to relatively lower VS content in septage and other opera-

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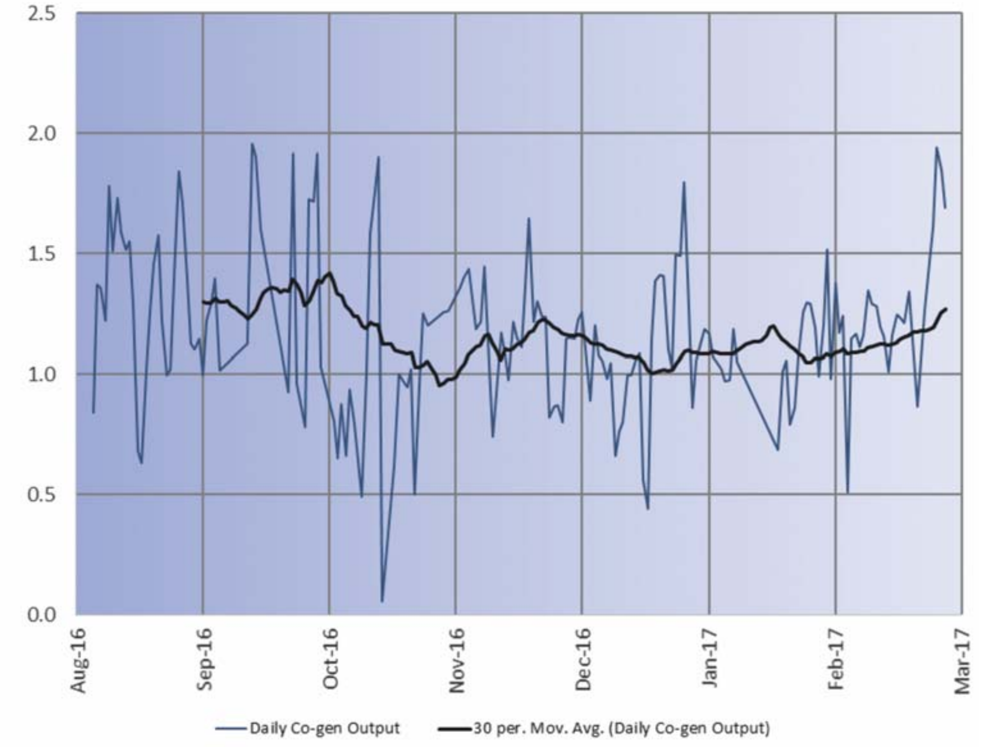

Figure 7. Electricity Production From the Cogeneration Facility

Figure 8. Basket Strainer Before (left) and After (right) Hot Water Flushing

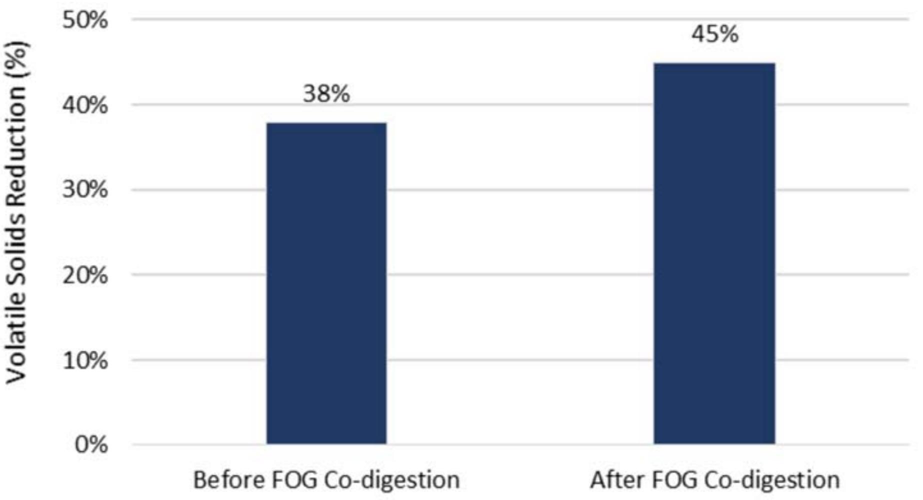

Figure 9. Volatile Solids Reduction Before and After Fats, Oil, and Grease Codigestion

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tional considerations (such as impact on dewatering). As such, consideration should be given to acceptance of haulers that do not mingle FOG loads with other waste streams.

- The FOG trucks received at the facility may contain larger solids, such as plastic forks, napkins, etc., which may clog the screens or pretreatment facilities. Haulers should be required to provide "clean" FOG (i.e., FOG should not contain extraneous items). Unloading activities should include a review of the contents of the trucks and, if possible, the prevention of miscellaneous debris from entering the FOG stream.
- One of the key lessons learned from the operation of the FOG facility was the positive impact of brief hot water flushing of the pipe and equipment used for unloading the FOG from the trucks (to the FOG storage tank) after unloading operations. The benefits of the flushing are twofold: it prevents clogging of pipes due to solidification of grease, and the flushing helps the removal of smaller particles trapped between the larger materials in the screens. Flushing enables this trapped material to be released and drained into the storage tank, resulting in reduced cleaning frequency for the basket strainers/screens and disposal of otherwise useful material, along with the disposal of screenings from the strainer. Figure 8 shows the basket strainer subsequent to FOG truck unloading before and after hot water flushing operation.
- Liquid level sensors are key instrumentation components for regulating the FOG receiving and dosing operations; as such, redundancy of these devices is important. From the start-up experience, liquid level monitoring devices based on laser technology were found to be better suited for such applications than sensors based on ultrasonic technology. Adequate clearance from the walls and liquid streams entering or exiting the tanks should be provided for installation of such sensors to minimize interference and improve accuracy.

Conclusions

Analysis of the digester performance data indicates that digesters responded well to codigestion of sludge with FOG. Digesters performed especially well in terms of stabilization of VA/alkalinity ratio. The step-feed approach for FOG dosing during start-up allowed for the digesters to acclimatize to the change in substrate and VS loading and to achieve stabilization of the VA/alkalinity ratio.

The addition of FOG to the digesters also appears to offer significant benefits in terms of VSR, with an increase in VSR from 38 percent without FOG codigestion to 45 percent after implementation of FOG codigestion (Figure 9).

The FOG addition also resulted in a boost in overall biogas production. The total biogas production increased by approximately 30 percent when comparing the average amount produced between April and July 2016 to the average amount produced prior to FOG addition (July to December 2015 baseline). The resultant energy production from the digester biogas yield ranged from 1 to 1.4 MW in the months following the start-up.

To increase the biogas generation, and subsequently, the energy production, the utility plans to continuously increase the FOG dosing to the digesters. Furthermore, it anticipates that the recently lengthened unloading areas will allow for larger FOG haulers to utilize the facility. This increase in FOG supply will ultimately provide higher FOG VS loading to the digesters.

The utility is also considering the introduction of an additional source of codigestion feed, such as high-strength food waste, which would further maximize the biogas production of the plant. Additional increases in biogas production will correspondingly increase the energy production of the facility.