Kennedy Jenks
2775 North Ventura Road, Suite 202
Oxnard, California 93036

FINAL
Digester Performance Evaluation

20 April 2022

Prepared for

Las Virgenes
Municipal Water District
4232 Las Virgenes Road
Calabasas, California 91302

KJ Project No. 2244203.00

Table of Contents

List of Tables

Table of Contents (cont'd)

List of Figures

Executive Summary

The Las Virgenes Municipal Water District (the District) engaged Kennedy/Jenks Consultants (Kennedy Jenks) to evaluate the operation of the anaerobic biosolids digestion system at the Rancho Las Virgenes (Rancho) Composting facility. The District owns and operates three fully functional, similarly sized anaerobic digesters and engaged Kennedy Jenks to evaluate the operation of these digesters to determine if the optimal operation of the system would engage two or three anaerobic digestion tanks.

The District provided Kennedy Jenks with the current process flow diagram for the Rancho facility, digestion system operations data from 2020 and 2021 and the current Operations & Maintenance Manual for the facility. Kennedy Jenks evaluated two key process parameters for anaerobic biosolids digestion systems (volatile solids loading and hydraulic detention time) and two system performance parameters (volatile solids reduction and gas production) to extrapolate operation from two digesters in service to three digesters in service.

The typical volatile solids loading for anaerobic digesters ranges between 0.07 and 0.12 pounds of volatile solids/cubic foot of digester volume/day (lbs VS/ft^3/d). If the volatile solids loading is too low, then the bacteria that work in the anaerobic digestion process to convert organic material to methane gas don't have enough "food" and thus operate inefficiently. If the VS loading is too high (above about 0.15 lbs VS/ft^3/d) the digestion system is thrown off balance and becomes more acidic, leading to poor performance.

The hydraulic detention time is a measure of how long the biosolids stay in the tank in anaerobic conditions. A typical design detention time for anaerobic digesters is 15 to 20 days. After about 25 days, the potential for additional VS reduction and gas production are minimal.

The actual data for the Rancho facility show a VS loading of 0.097 lbs VS/ft^3/d for two tanks in service and 0.068 lbs VS/ft^3/d for three tanks in service. The hydraulic detention time for two tanks in service ranges from 28 to 32 days and for three tanks in service it is over 40 days.

Based on these parameters, operation of two tanks is recommended for the Rancho facility. Our conclusion is that operation of three tanks will not result in substantively greater VS reduction or gas production over the operation of two tanks. Two tanks in service will provide optimal process performance at a reduced operating cost. It will also enable the District to take a tank out of service for maintenance or cleaning without impacting the performance of the anaerobic digestion system at Rancho.

Section 1: Purpose and Scope of Evaluation

The District owns three, fully functional, similarly sized digesters. Considering the trend of decreasing sludge flows and the need to maintain functionality of all three digesters, it is important to evaluate if two-digester operation is overall most beneficial for the District.

1.1 Existing Solids Treatment Facilities

Existing digestion facilities at the Rancho site of the District include three digesters. Digesters 1 and 2 have a capacity of 1.16 million gallons (MG) and were constructed in 1993. Digester 3 has a capacity of 1.1 MG and was constructed in 2013. The key drivers for the construction of Digester 3 included redundancy, growth in the service area and subsequent anticipated increase in the wastewater solids of 33% in 2030. The additional digestion capacity would also allow for considering future co-digestion.

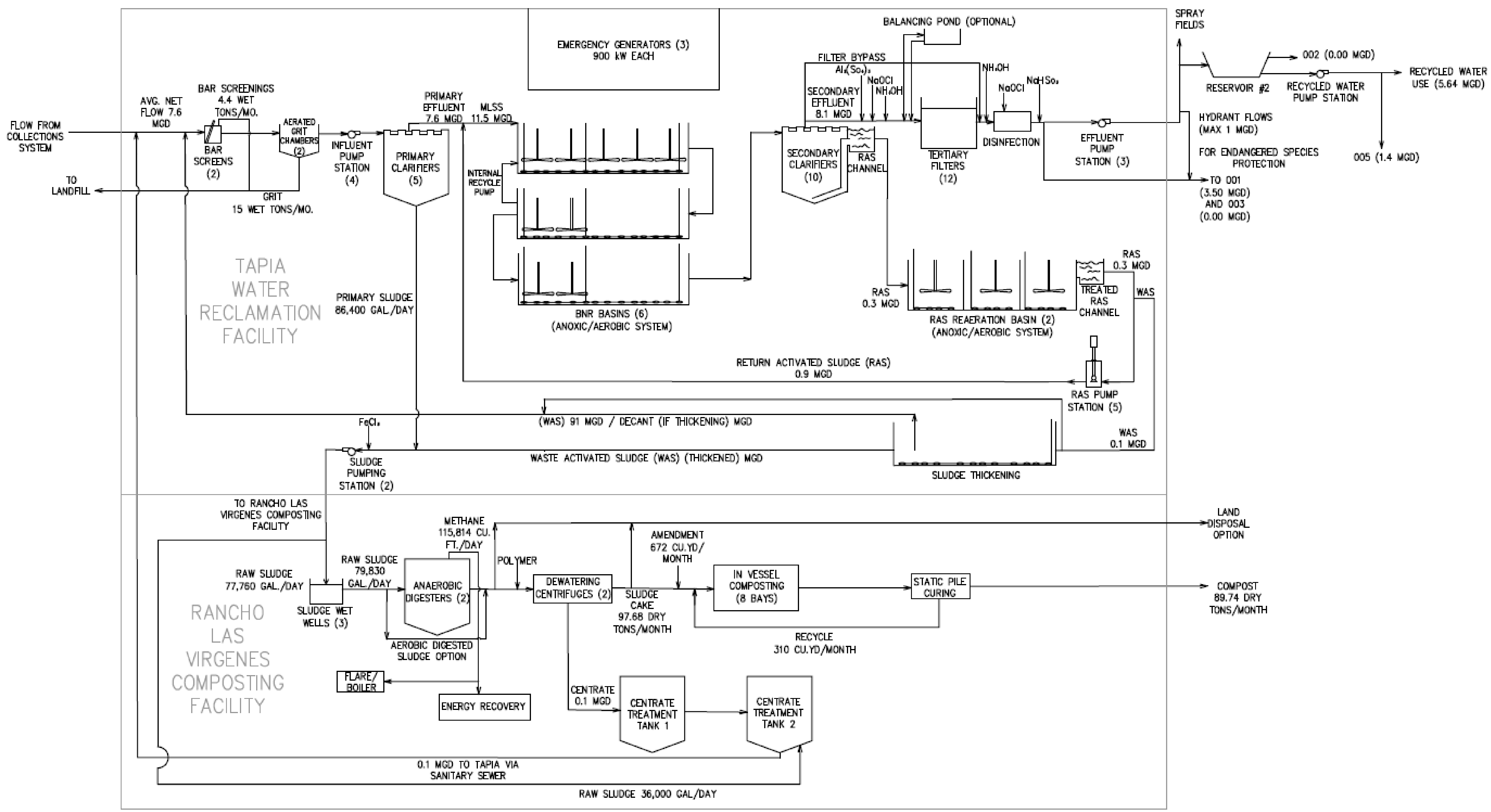
The WAS from the secondary treatment system is wasted into the headworks and settles out in the primary clarifier as a combined sludge. The sludge is then sent to the sludge wet wells. The sludge flow to the digesters is equally split between the two digesters in operation.

After digestion, sludge is dewatered by centrifugation. Sludge is drawn from the digesters in cycles (Digesters 1 and 2 have five draw off pipes each, while Digester 3 has one) into a digested sludge wet well and then pumped to the centrifuge. The centrate is treated in two treatment tanks and then returned to the headworks at the Tapia Water Reclamation Facility. This process flow is presented in Figure 1. The dewatered biosolids are composted or land applied.

Previously, the digester gas was conveyed to a gas handling system and then to a cogeneration engine. However, the engine is no longer functional. The digester gas is currently flared or used fire a boiler which uses the hot water in a closed loop to heat the digesters through a heat exchanger.

Currently, the District is experiencing fluctuation in the wastewater flow to the facility and therefore, the sludge flow has reduced from the past flow of 100,000 gpd to approximately 50,000 gpd. As a result, only two digesters are in operation.

Figure 1: Process Schematic



---FLOW VALUES BASED UPON ANNUAL AVERAGES FROM 2017 TO 2021
---VALUES IN PARENTHESES ( ) REFLECT THE NUMBER OF UNITS/FACILITIES

1.2 Scope of the Evaluation

This evaluation analyzed past data and evaluated digester performance. Available information on the effect of increased sludge retention time and other relevant parameters resulting from increased digester volume were compiled. The evaluation included analyses of solids reduction, biogas production and other digester health parameters as well as digested sludge dewatering based on available data from the plant and information collected from literature.

The following aspects of anaerobic digester treatment were evaluated based on discussions with the District:

1. Potential impacts if a third digester is added into full time operation.
2. Recent digester operations and performance history from 2020-2021 data.
3. Future co-digestion considerations.

Section 2: Project Approach

Digester process, operations evaluations and subsequent recommendations were based on background documentation and plant operating data provided by District staff at the request for information by Kennedy Jenks. This section presents the background documentation and data used for the development of this evaluation.

2.1 Information Received

The following information was received from District staff:

- Operations and Maintenance Manual for the Anaerobic Digestion Process at the Rancho Las Virgenes Solids Handling Facility, Volume 2, April 1995
- Current solids operational procedures

2.2 Operational Data Received

Plant digester operational information included selected data from 2019 through 2021 and included the following data sets:

- Daily raw sludge flows to the digesters (2 online – Digesters 1 and 3) (gpd)
- Tapia to Rancho Sludge Total Solids (TS) (%)
- Digester 1 and 3 Gas Flow (ft^3/d)
- Digester 1 and 3 Temperature (deg F)
- Digester 1 and 3 Level (ft)
- Digester 1 and 3 TS and Volatile Solids (VS) (%)
- Digester 1 and 3 pH
- Digester 1 and 3 VA/ALK
- Digester 1 and 3 Detention Times
- Digester 1 and 3 VS Reduction (%)
- Digester Gas Quality - CH_4, CO_2, and H_2S
- Polymer Demand
- Dewatered Cake TS (%)

Calculations such as digester VS loading, unit gas production, volatile solids reduction (VSR) by mass balance as well as Van Kleeck method were performed. These parameters were compared for two vs. three digesters in operation.

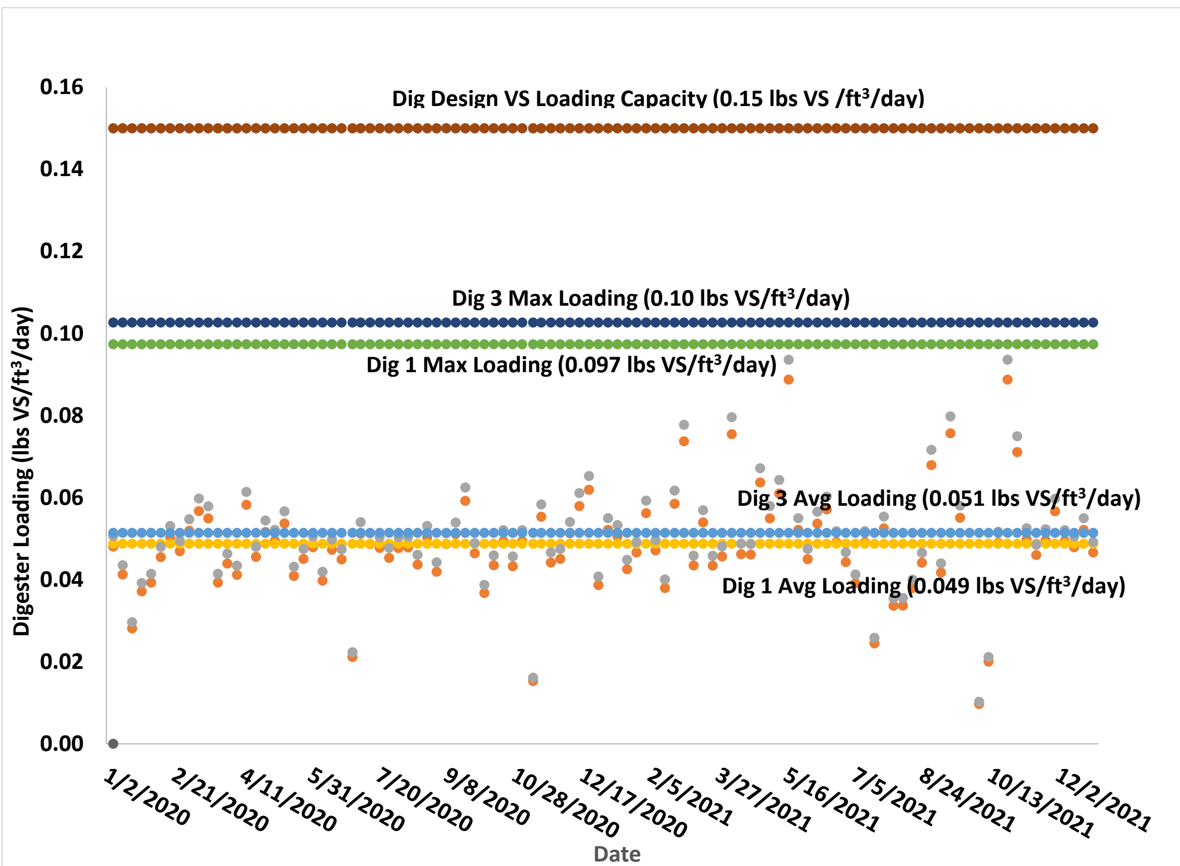
Section 3: Data Analyses

This section presents in detail current digester data analyses for the various operational parameters as well as the impact of operation of two vs. three digesters on the digesters.

3.1 Digester Volatile Solids Loading

The loading rate of a digester refers to the amount of organic material fed to a digester per day per unit liquid volume of the digesters. Data provided by the District as described in Section 2 was used in calculating VS loading to each of the digesters. Figure 2 shows the digester loading to the 2 digesters over the two years i.e., 2020 and 2021.

Figure 2: Digester Loading with Two Digesters (Dig. 1 and 3) in Operation (2020-2021)

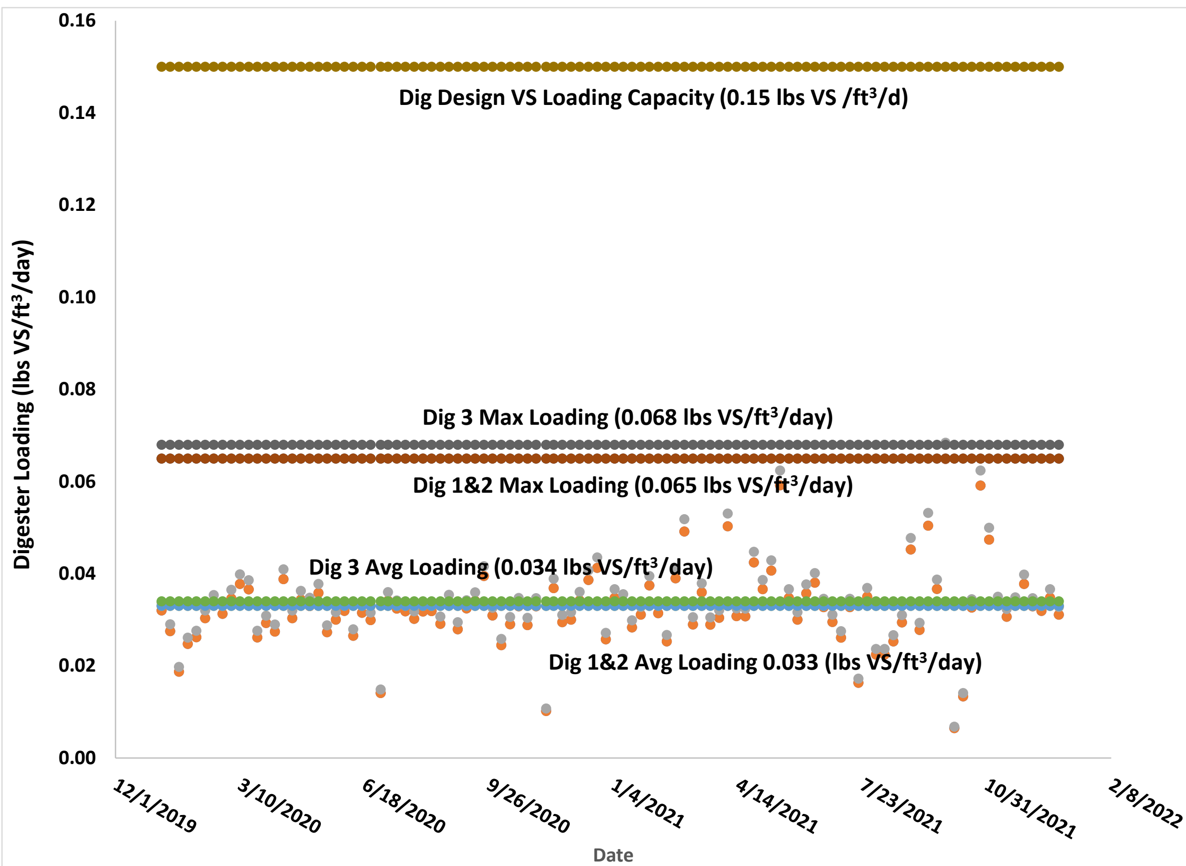


As seen in Figure 2, the maximum loading of Digester 1 and 3 (volumes 1.16 and 1.1 MG respectively) over the two years studied was reported to be around 0.1 lbs VS/ft^3/day. The average loading was almost half the maximum value for each digester considered.

Using the same flows, loads and the solids characteristics, if Digesters 1 and 2 were in operation (both 1.16 MG in volume), average loading of each digester would be 0.049 VS/ft^3/day with a max loading of 0.097 VS/ft^3/day. All of these loadings are at least 35 percent lower than the value of 0.15 lbs VS/ft^3/day, which is considered to be the upper design limit of VS loading to digesters (Kennedy Jenks 2012).

If the current flows, loads and the sludge quality are assumed to be the same, with three digesters in operation, the VS loading to each digester is further reduced. Figure 3 presents the VS loading if three digesters were in operation.

Figure 3: Digester Loading with all Three Digesters in Operation (Potential Scenario)



If three digesters are in operation, the maximum loading would be 35 percent lower and the average loading 40 percent lower than if two digesters were in operation. This indicates that two digesters can operate very reliably for current loadings with substantial additional capacity to treat more organic loading.

The upper limits for volatile solids loading (0.15 lbs VS/ft^3/day) depicts the highest loading where the digester can potentially operate without instability. VS overloading and inhibition is one of the main causes of volatile fatty acid (VFA) accumulation and the subsequent acidification of digesters (Higgins and Rajagopalan, 2017). In these cases, there is an imbalance in the steps occurring in anaerobic digestion so the rate of VFA and hydrogen production by acidogenic and acetogenic bacteria exceeds the rate of VFA consumption by methanogens. Methanogens are generally more sensitive to inhibiting compounds than the above-mentioned bacteria, so an increase in inhibiting compounds such as VFA, ammonia or sulfides can in-turn lead to a process imbalance and digester souring. Such conditions could be accompanied by a drop in the pH.

The capacity of the digester to resist pH changes is called the buffering capacity. The buffering capacity of an anaerobic digester is determined by the amount of alkalinity present in the system, from both the influent sludge and that produced within the digester. Well-operated, robust digesters are considered to be sufficiently buffered due to the effect of alkalinity formed during fermentation (Higgins and Rajagopalan, 2017).

Based on the discussion above, VS loading is a process characteristic, and not just a digester feed parameter. Though such typical limits of VS loading are available in literature, VS loading is directly related to the digester process parameters and chemistry, namely, pH, alkalinity and the VFA`s potentially produced from VS destruction. Though overloading or excessive VS can cause inhibition, lower solids loading is not operationally beneficial to digesters. More dilute solids feeds and thus lower TS and VS in feed lead to less alkalinity and reduced buffering capacity. In order to have a robust microbiology within the digester, an optimum, constant VS supply is necessary, which is accomplished by having only two digesters in operation.

3.2 Solids Detention Time

Data provided by the District, as described in Section 2, was used in calculating the detention times in each digester. Table 1 compares the digester hydraulic loading to the 2 digesters (Digester 1 and Digester 3) over the two years i.e., 2020 and 2021 as well as if Digesters 1 and 2 were in operation.

Table 1: Detention Times for Two Digesters (2020 and 2021)

	Average Detention Time (days)	
Year	**Dig 1**	**Dig 3**
2020	28.7	27.2
2021	31.6	29.9
	Dig 1	**Dig 2**
2020	28.7	28.7
2021	31.6	31.6

The detention times range between 27 and 32 days which is in the range of design values of mesophilic digesters.

Table 2 provides the detention times when all three digesters are in operation.

Table 2: Detention Time for all Three Digesters in Operation (Potential Scenario)

	Average Detention Time (days)		
Year	**Dig 1**	**Dig 2**	**Dig 3**
2020	43.2	43.2	40.9
2021	47.3	47.3	44.8

As seen from Table 2, the decrease in loading rates if three digesters were in operation results in higher detention times in each digester. As a parameter that is related to the loading rate, a shorter HRT corresponds to a higher loading rate, as seen from the data discussed in this section.

The main function of the detention time in the digester is to enable the anaerobic biological processes to first convert volatile organics to organic acids and then to convert these organic acids to methane and other fermentation byproducts. These processes produce methane, reduce the overall solids content of the biosolids, and deactivate pathogens in the sludge to make it safe for land application. For pathogen destruction, the minimum allowable detention time is 15 days if a constant temperature of at least 95 degrees F can be maintained in the digester (Verma et al., 2006).

Generally, mesophilic digestion is designed to be accomplished within 15–30 days. For mesophilic digestion of municipal wastewater sludge only, longer HRTs are not necessary. Other wastes with lignocellulosic components need longer HRTs for their digestion (Shi et al., 2017). Typically, primary and secondary wastewater solids breakdown in the first few days in a well-operated, well-mixed, conditioned, and robust digester operating in the mesophilic temperature regime. Research has shown that higher SRT increases VS reduction only to a point and longer detention times do not provide additional significant VS reduction benefit. In lab-scale digesters, 50% VS reduction was obtained at a 10-day SRT itself and on an average, about 6% additional VS destruction from 20 days to 30 days and 8% from 30 days to 40 days was observed (Verma et al., 2006). This small increase in VS destruction in literature has typically been observed in smaller bench and lab-scale digesters. Such increases are not typically observed in full-scale operation as it tends to be more erratic due to plant influent characteristics. Typically, shorter HRTs in the range of 15-30 days allow for increased mesophilic process efficiency, as longer HRTs are not necessary for municipal wastewater sludges, thus indicating that its sufficient to have only two digesters in operation for optimum performance.

3.3 Digester Performance – Solids Content, Gas Production, VSR and Unit Gas Production

3.3.1 Solids Content

3.3.1.1 Influent Sludge Solids Content

The feed sludge characteristics varied during the project period due to changes in influent sludge quality that occurred over time. The average TS and VS values measured are shown in the figure 4 below.

Figure 4: Influent Solids Content to the Digesters

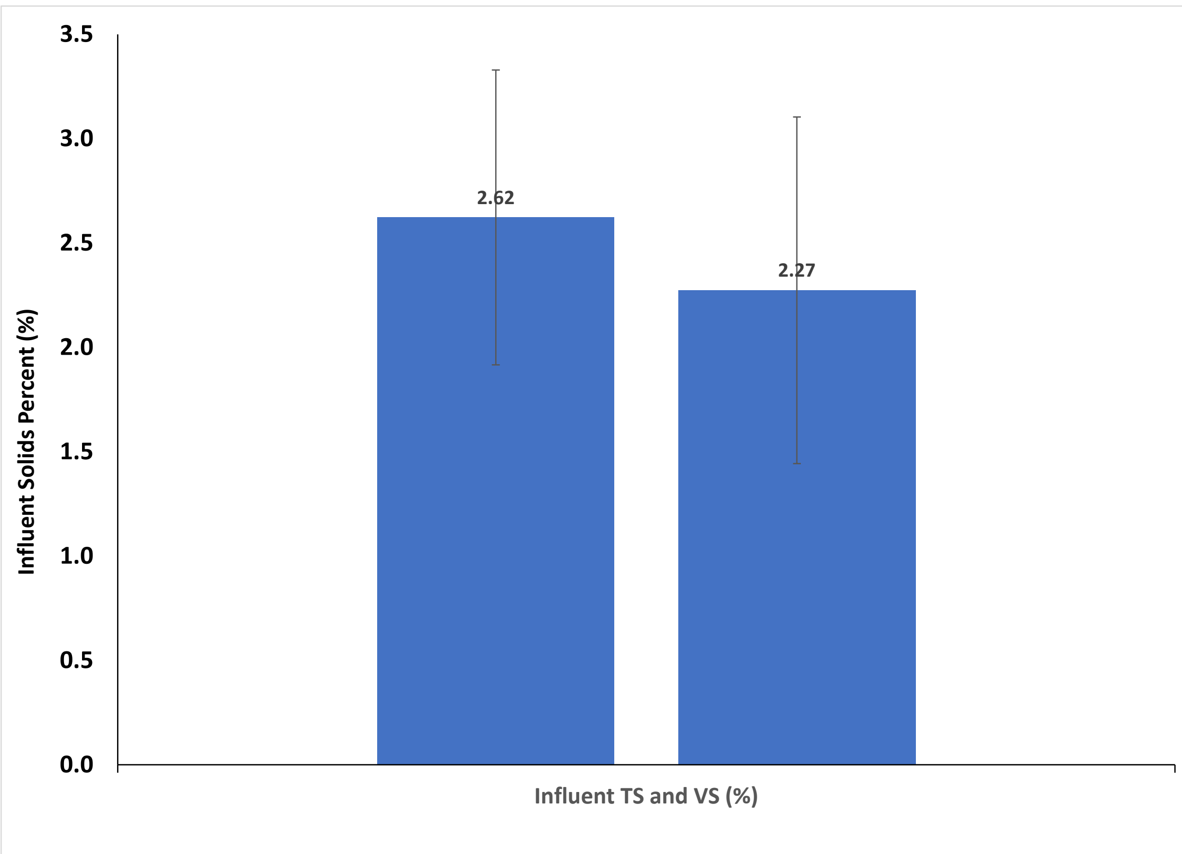


Figure 4 above shows the percent TS and VS for the feed samples. The TS was approximately 2.6%. The percent VS of the digester feed samples was 2.2%. The variation observed between different samples (standard deviation) is likely typical of the day-to-day changes in influent wastewater characteristics.

TS is an important attribute of digester operation. Typical solids concentration in the feed to the digester is in the range of 4 - 6 %. The data analyzed here indicate a more dilute feed. Feeding dilute sludge typically reduces the retention time, volatile solids destruction, and consequently reduce methane production. Lately, high-TS anaerobic digestion has received a considerable amount of attention, mainly on account of lower digester footprints as well as lower heating needs. Improved biogas yields were reported in continuous high-TS digesters compared to low-TS digesters operating on the same retention time (Duan et al., 2012).

Based on this discussion, it is important to have a solids feed to the digester in the range of 2.5 - 4.5%.

3.3.1.2 Digester Solids

Data from the digester effluent TS and VS concentrations were obtained. The results from these analyses are shown in Figure 5.

Figure 5: Solids Content in the Digester Effluent

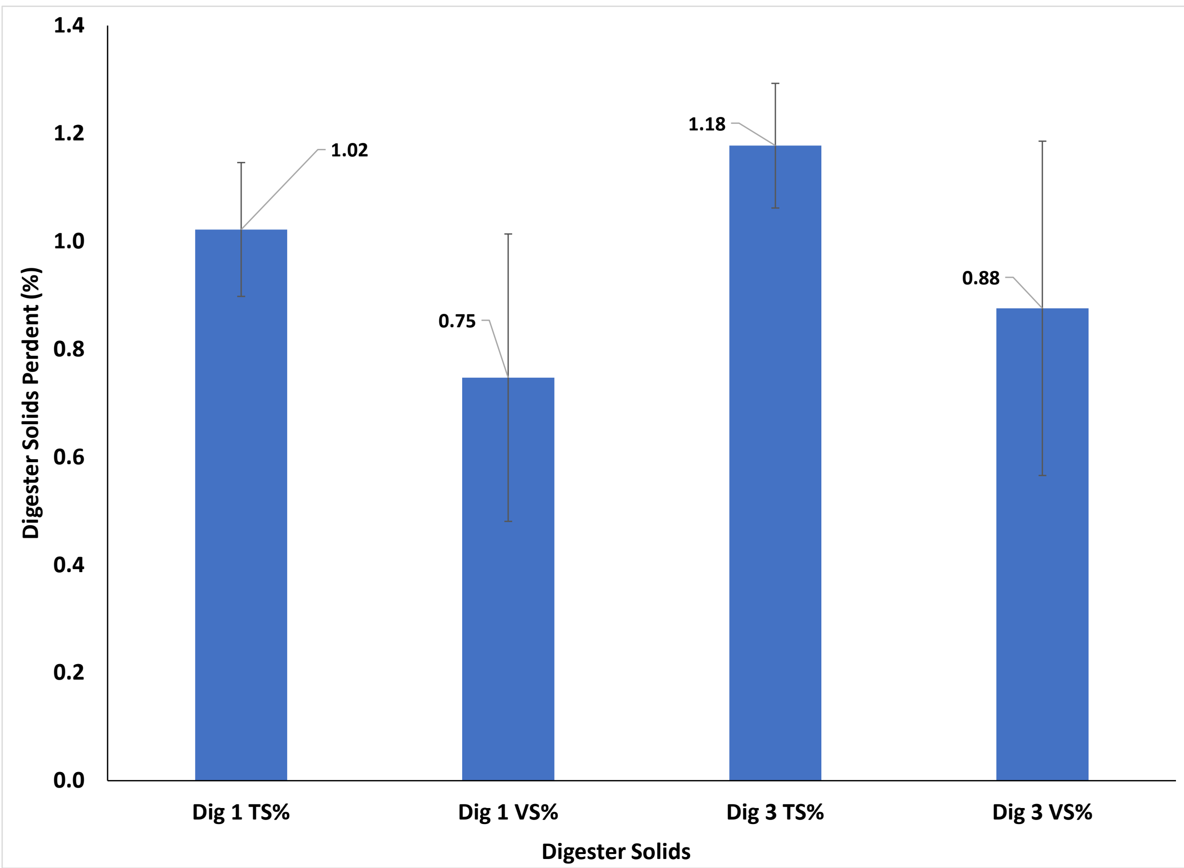


Figure 5 shows that the digester solids concentration is lower than 1.2% in both digesters. Typical solids concentration of digested sludge is 1.5 – 3.5 %. The digested sludge concentration is lower than this typically reported levels. This low solids concentration is likely due to dilute sludge feed to the digester.

Table 3 summarizes what TS and VS loading was applied in the sludge feed during each test, and what the resulting VS reduction (VSR) was calculated to be, based on the digester performance.

Table 3: Feed Sludge Solids and Digester Solids during 2020 and 2021

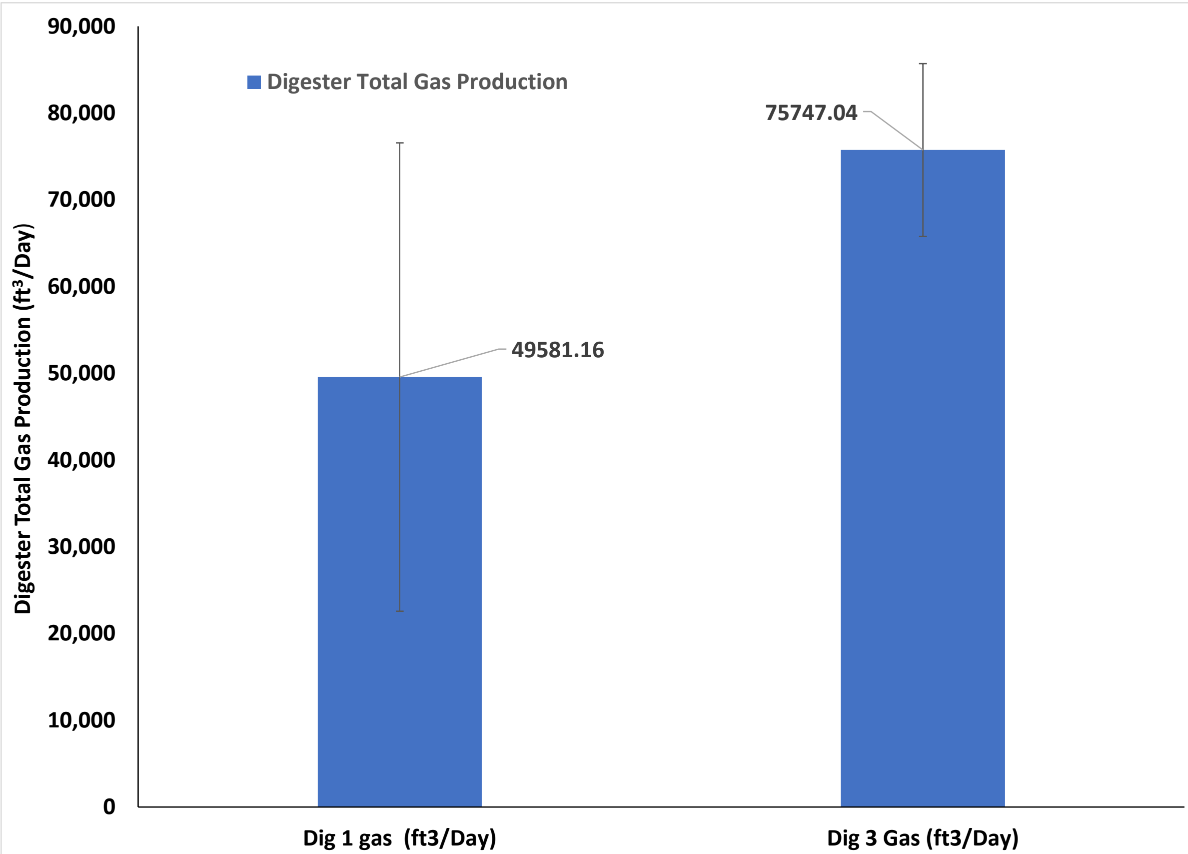
Digester	Influent Sludge TS (lb/d)	Influent Sludge VS (lb/d)	Feed Sludge VS/TS Ratio	Dig VS Loading (lbs VS/ft^3/d)	Dig Overall VS/TS Effluent Ratio
Digester 1	8724	7562	0.87	0.049	0.73
Digester 3	8724	7562	0.87	0.051	0.73

Digester 3 VS loading is only marginally higher than digester 1 (about 4%). The average VS/TS ratio for the digester feed sludge was ~0.87 for both digesters. The digester effluent VS/TS was 0.73 for both digesters, indicating similar performance. The digested VS results indicate that the percent VSR and gas production should be similar. These results are further discussed below.

3.3.2 Total Gas Production, VS Reduction (VSR) and Unit Gas Production

The total gas production was measured from each digester and is shown in Figure 6.

Figure 6: Total Gas Production from Each Digester (2020-2021)



In general, the increased VS loading in Digester 3 should result in higher total gas production in this digester. But gas production in Digester 3 is 53% greater than digester 1 for similar performance and only a 4% loading increase. This is because Digester 1 gas production data had a significant number of days where values were not recorded and resulted in much lesser total gas. However, the performance is similar to that of Digester 3, as indicated by the digester VS/TS and the VSR.

The gas production was normalized based on the VSR taking place and is summarized in Table 4.

Table 4: VSR and Unit Gas Production during 2020 and 2021

Dig 1 VS Destroyed (%) Mass Balance	Dig 1 Van Kleeck (calc.)	Dig 1 Unit Gas (ft^3/lb VSR)	Dig 3 VS Destroyed (%) Mass Balance	Dig 3 Van Kleeck (calc.)	Dig 3 Unit Gas (ft^3/lb VSR)
65.6 ±13.6	57.0 ±14.5	9.7± 12.3	65.5 ± 14.4	54.7±17.2	15.0 ±12.7

The average VSR for Digesters 1 and 3 was 57% and 54.7% respectively, based on Van Kleeck method estimation. The VSR was also calculated using the mass balance method in order to estimate the unit gas production. A higher VSR was estimated using the mass balance method as listed in Table 4. Typically, Van Kleeck leads to an underestimation of the VSR because it does not account for the fixed solids changes that may occur in the digester. When gas production was normalized based on the VSR for each digester, results indicated that gas production in Digester 1 was lower per unit of VS reduced compared to Digester 3. The unit gas production is estimated to be 15 ft^3 of gas produced/lb VSR in Digester 3, which is in the range reported in literature. Typically, literature reports a range of 13-18 ft^3 of gas produced/lb VSR for municipal wastewater sludge (Gray, et al., 2008). Digester 1 was lower at 9.6 ft^3 of gas produced/lb VSR. The reason for the lower unit gas production in Digester 1 is attributed to the absence of total gas production data readings for a significant number of days.

3.4 Dewatering

The factors that affect dewatering after anaerobic digestion are complex and related to several sludge physical-chemical aspects. The dewaterability of biosolids is strongly dependent on the biosolids' characteristics such as the VS content (Skinner et al., 2015), extra cellular polymeric substances (EPS), and soluble microbial products (Nghiem et al., 2017), cation concentrations (Higgins and Rajagopalan, 2017), among other operational factors such as the shearing of flocs caused during dewatering and polymer-sludge interactions. The following dewatering and biosolids parameters are potentially impacted by digester operations:

1. **Optimum polymer dose (OPD):** The OPD for dewatering was determined by developing a curve based on the capillary suction time (CST) at a given polymer dose. Briefly, CST is the time taken to dewater and is typically measured in seconds (Novak 2006). The main uses of CST include assessing the effects of conditioning on sludge filterability as well as determining the optimum dose of polymers for dewatering processes (Novak 2006). The dose producing the sample with the lowest CST is typically considered as the optimum polymer dose. The calculated polymer demand is 15.1 lb/Dry Ton for the period of 2020-2021.

2. **Percent TS of the dewatered cake:** an estimate of the net mass of cake generated (that is, mass of sludge requiring disposal). The dewatered TS content of the digesters is an indicator of the mass of sludge generated for hauling from the plant. If the dewatered cake solids (i.e., percent TS in cake) is higher, the mass of sludge to be hauled will be lower.

Table 5: Digester Solids and Dewatered Solids Content during 2020 and 2021

Sample	Average Solids (% TS)
Avg. Dig 1 Effluent Solids	1.02
Avg. Dig 3 Effluent Solids	1.18
Avg Dewatered Cake Solids	22.02

Table 5 shows a dewatered cake solids content of 22% in spite of lower than typical digester solids of ~1.2%.

3. **Odor production from dewatered cake:** Cake odors are an important biosolids quality aspect, especially in cases where utilities beneficially reuse their dewatered cake through land application (Novak 2006). Therefore, the effects of co-digestion on cake odor are an important parameter to be evaluated. Typically, compounds associated with the generation of odor are the total volatile organic sulfur compounds (TVOSCs) that act as surrogates for cake odors. Currently cake odors have not been evaluated and data from the District is not available.

Dewatering is a complex process. Limited literature on the relationship of SRT and dewatering shows that SRT has been shown to have insignificant effect on biosolids dewaterability in terms of the cake TS (Zhang et al., 2020, Verma et al., 2006). In general, increasing SRT beyond 15 days provides little benefit on biosolids quality as well as the anaerobic digestion performance. No significant variance on odor emission was also observed for biosolids stabilized at different SRTs (Zhang et al., 2020). It has been reported that polymer dose and shear intensity involved in dewatering practices are factors that show significant impact on biosolids dewaterability and cake odor emission. This discussion indicates that higher SRTs from operation of three digesters may not necessarily be beneficial to dewatering.

Section 4: Recommendations and Future Co-digestion Plans

1. For optimal digester performance, it is recommended to operate two digesters for the current incoming flows and loads to the plant.

2. It is recommended to thicken the sludge feed to the digesters to remove water and feed a solids concentration of 4 – 6 % solids to the digesters. This could help achieve a solids concentration of digested sludge of 1.5 – 3.5 % solids, which may help improve dewatering and reduce polymer demand.

3. It is recommended to rotate into service, the equipment such as mix pumps, heat exchangers, sludge recirculation pumps, etc. in the off-line digester into service quarterly or as needed, with the exception of the valves that allow digestate from the other digesters into the off-line digester.

4. The digesters are designed for redundancy and have substantial excess capacity with regard to volatile solids loading. It is recommended to consider future co-digestion of high-strength wastes (HSW) such as fats, oil and grease (FOG) and food waste (FW) in order to:

   (a) utilize the excess digestion capacity

   (b) increase VS reduction and biogas production

   (c) potentially reduce the quantity of biosolids produced

   (d) generate more power if there are options for converting biogas to energy

Most HSW typically has higher methane potentials than municipal wastewater sludge. Multiple studies have shown that the co-digestion of HSW with sewage sludge can significantly increase biogas production (Higgins and Rajagopalan, 2017; Mata-Alvarez et al., 2011, 2014). Such enhancement in digestion and gas yield are mainly due to synergistic effects (Higgins and Rajagopalan, 2017). The synergistic effect is defined as a phenomenon where the co-digestion of HSW with sewage sludge results in better performance than when the substrates are digested separately. These effects have been reported in several studies for lab- and bench-scale systems as well as full-scale systems conducted by Kennedy Jenks (Higgins and Rajagopalan, 2017; Rajagopalan, et al., 2019) where an increase in VSR ranged between 3 - 11.5% and gas production increases ranged from 3-58% for the addition of FOG and FW.

In addition to an increase in VSR and consequently an increase in gas production, several side effects may occur when additional HSW like FOG and FW are added to a digester. Past research as well as full-scale operation by Kennedy Jenks has shown beneficial side effects due to co-digestion, such as improvements in dewaterability as measured by cake solids and a decrease in cake odors (Rajagopalan et al., 2019, Higgins and Rajagopalan, 2017). In Kennedy Jenks` past research, correlations were developed for dewatered solids data from co-digestion studies, where the normalized percent change in wet solids leaving the plant was plotted against the percent change in the VS loading to the digester due to the different HSWs. A majority of these HSWs were pre- and post-consumer FW. In general, the post-consumer FW showed a consistent trend with lower wet cake production up to about 15-25% additional VS loading from these FW (Higgins and Rajagopalan, 2017). Addition of FOG resulted in a net reduction of 17.7% in the cake requiring disposal in a full-scale study (Rajagopalan et al., 2019). However, co-digestion tests performed through addition of higher FOG loadings did not appreciably improve dewatering in the same study. Addition of FW to full-scale digester resulted in a net reduction of 11.5% in the cake requiring disposal, compared to dewatering of sludge digested without any FW addition (Rajagopalan et al., 2019). In other published full-scale studies, the co-digestion of FOG with municipal sludge decreased the quantity of solids produced by 33% and improved biosolids dewaterability (York and Magner, 2009).

Such reduction in the quantity of biosolids produced can be achieved by the strategic addition of HSWs. This will allow for synergistic interaction of HSW and sludge solids to improve dewatering and lower the mass of cake solids requiring disposal. This approach has been readily adopted for co-digestion in several wastewater treatment facilities but requires some bench-scale testing to optimize the HSW: sludge loading ratio in the digesters, prior to implementation in full-scale.

Implementation of co-digestion can bring economic benefits to the District by providing more biogas for energy conversion, revenue from tipping fees from HSW receiving as well as the cost savings for land application due to potential lower biosolids production. However, prior to implementing HSW co-digestion, the District also needs to build new infrastructure for gas cleaning, gas storage and energy recovery and utilization as well as for HSW receiving and processing. So, a detailed cost-benefit analyses must be conducted to weigh the economic returns for implementing co-digestion.

References

Aichinger, P., Wadhawan, T., Kuprian, M., Higgins, M., Ebner, C., Fimml, C., Murthy, S., and Wett, B. (2015) Synergistic co-digestion of solid-organic-waste and municipal-sewagesludge: 1 plus 1 equals more than 2 in terms of biogas production and solids reduction. Water research, **87**, 416–423.

Duan, N.; Dong, B.; Wu, B.; Dai, X. High-solid anaerobic digestion of sewage sludge under mesophilic conditions: Feasibility study. Bioresour. Technol. 2012, 104, 150–156.

Gray, D. M., Suto, P., and Peck, C. (2008) Anaerobic digestion of food waste. East Bay Municipal Utility District Report. [online] http://www.gaialibrary.org/system/files/Anaerobic%20Digestion%20of%20Food%20Waste.pdf.

Higgins, M.J. and Rajagopalan, G. (2017) Understanding Impacts of Co-Digestion: Digester Chemistry, Gas Production, Dewaterability, Solids Production, Cake Quality and Economics. Water Environment & Reuse Foundation, WE&RF ISBN: 978-1-94124-282-7.

Kennedy Jenks Consultants 2012. Draft Preliminary Design Report, Rancho Las Virgenes: Design of a Third Digester. Las Virgenes Municipal Water District, Triunfo Sanitation District Joint Powers Authority. January 23, 2012.

Labatut, R. A., Angenent, L. T., and Scott, N. R. (2011) Biochemical methane potential and biodegradability of complex organic substrates. Bioresource technology, **102**(3), 2255–2264.

Mata-Alvarez, J., Dosta, J., Macé, S., and Astals, S. (2011) Codigestion of solid wastes: a review of its uses and perspectives including modeling. Critical Reviews in Biotechnology, **31**(2), 99–111.

Mata-Alvarez, J., Dosta, J., Romero-Güiza, M. S., Fonoll, X., Peces, M., and Astals, S. (2014) A critical review on anaerobic co-digestion achievements between 2010 and 2013.Renewable and Sustainable Energy Reviews, **36**, 412–427.

Nghiem, L. D., Koch, K., Bolzonella, D., and Drewes, J. E. (2017) Full scale co-digestion of wastewater sludge and food waste: Bottlenecks and possibilities. Renewable and Sustainable Energy Reviews, **72**, 354–362.

Novak, J. T. (2006) Dewatering of sewage sludge. Drying technology, **24**(10), 1257–1262.

Rajagopalan, G; Subramanian, B; Safaee, H & Holloway, R. 2019. *Lowering Food Waste Co-Digestion Costs Through an Innovative Combination of Preprocessing Technique and a Strategy for Cake Solids Reduction.* California Energy Commission. Publication Number: CEC-500-2020-069.

Shi X.-S., Dong J.-J., Yu J.-H., Yin H., Hu S.-M., Huang S.-X., Yuan X.-Z. Effect of hydraulic retention time on anaerobic digestion of wheat straw in the semicontinuous continuous stirred-tank reactors. BioMed Res. Int. 2017.

Verma, N., Park, C., Novak, J. T., Erdal, Z., Forbes, B., & Morton, R. (2006). Effects of anaerobic digester sludge age on odors from dewatered biosolids. Proceedings of the Water Environment Federation, *2006*(12), 1119-1141.

York, R. V. and Magner, J. A. (2009) Increasing CHP productivity while reducing biosolids volume and climate changing gasses. Proceedings of the Water Environment Federation, **2009** (9), 6639–6651.

Zhang, D., Strawn, M., Broderick, T., Novak, J. T., & Wang, Z. W. (2020). Effects of anaerobic digester solids retention time on odor emission and dewaterability of biosolids subjected to various shear intensities, polymer doses, and storage duration times. Environmental Science: Water Research & Technology, *6*(6), 1588-1596.

Zhang, W., Zhang, L., and Li, A. (2015) Anaerobic co-digestion of food waste with MSW incineration plant fresh leachate: process performance and synergistic effects. Chemical Engineering Journal, **259**, 795–805.