Resource Recovery & Electrical Energy (R2E2)
Project Case Study
Utility: NEW Water,
the brand of the Green Bay Metropolitan Sewerage District
Location: Green Bay Facility, Green Bay, WI

OVERVIEW

NEW Water, the brand of the Green Bay Metropolitan Sewerage District, has completed a new solids processing facility at their Green Bay Facility (GBF) in Green Bay, Wisconsin. This facility is permitted to treat 49.2 MGD of wastewater and process biosolids from the GBF and waste activated solids from their other wastewater facility, the De Pere Facility (DPF), which is permitted to treat 10.0 MGD.

This case study is intended to provide information summarizing the planning and alternative selection, system details, and start-up and ongoing operational results associated with anaerobic digestion, incineration performance, and electrical energy generation for NEW Water's Resource Recover and Electrical Energy (R2E2) system.

PLANNING AND ALTERNATIVE SELECTION

NEW Water, like many other wastewater utilities, faces many challenges in providing efficient, cost-effective services including increasingly stringent environmental regulations, growing communities, and aging infrastructure. In 2008, NEW Water initiated a planning process to address three main drivers. Those drivers were aging solids processing infrastructure, compliance with pending Federal Clean Air Act Maximum Achievable Control Technology (MACT) air pollution regulations for sewage sludge incinerators (SSIs) that became effective in 2016, and increased solids processing capacity after taking over operation of the DPF.

Between 2008 and 2011, NEW Water developed a Solids Management Facility Plan that evaluated numerous solids processing technologies and process trains to respond to these issues. Seventy-three solids unit processes were considered. After some processes were eliminated, fifty-two-unit processes were used to develop seventeen process configurations. Of these seventeen configurations, the following six alternative configurations were selected and evaluated in detail:

- Alternative 1: Incineration with Energy Recovery
- Alternative 2: Digestion with Thermal Processing
- Alternative 3: Digestion with Thermal Processing and Electrical Generation
- Alternative 4: Conventional Composting
- Alternative 5: Incineration with Drying

- Alternative 6: Rehabilitate (Existing) Multiple Hearth Furnaces

Alternative 3B: Digestion with Thermal Processing and Electrical Generation was selected and later named the Resource Recovery and Electrical Energy Project, or R2E2.

Primary drivers for the selection of the R2E2 process include:

- NEW Water is located in Brown County, WI which has significant pressure from agricultural uses, thus making a land management approach to biosolids challenging.

- The existing multi-hearth furnaces would not have met "new" source MACT regulations triggered by updates and repairs exceeding the 50% of original cost threshold.

- The R2E2 process had the ability to manage long-term operational costs through generation of electricity and heat recovery.

SYSTEM DETAILS

The R2E2 process, shown in Figure 1, is comprised of mesophilic anaerobic digestion, dewatering, drying, fluidized bed incineration, and air pollution control. Anaerobic digestion was chosen as a first processing step to reduce the amount of solids to be incinerated and to generate biogas for combined heat and power (CHP). High strength liquid organic wastes would be co-digested to enhance biogas production and maximize power production and waste heat utilization. Dewatering using centrifuges, followed by an indirect heat disc dryer and fluid bed incineration was selected as the most efficient method of managing the biosolids. A struvite recovery system was also installed to provide nutrient harvesting from the dewatering centrate and filtrate from thickening phosphorus-released WAS streams. A struvite recovery system will also avoid the operational issues generated by the anticipated nuisance struvite formation. Commissioning and performance testing of the R2E2 system, except for nutrient recovery, were completed in 2018.

The fluid bed incinerator (FBI) system is equipped with a partial or scalping dryer, utilizing waste heat recovered from the FBI using thermal oil to achieve autogenous combustion. The FBI equipment train was procured directly by NEW Water and assigned to the construction contract while the CHP, dewatering centrifuges, and struvite recovery equipment was preselected during design. The balance of plant design was completed in 2014, with construction commencing in August 2015. Commissioning and performance testing of the R2E2 system, except for struvite recovery, were completed in 2018.

Figure 2 shows a summary of the system design energy distribution and usage based on the assumed operational conditions for the design year of 2035 at annual average wastewater flow conditions, 20 years after the initial commissioning. The R2E2 project is anticipated to generate more than 65% of the GBF projected electrical power requirements in 2035 using biogas only and up to 85% with the use of supplemental natural gas to achieve the full CHP loads. With the system thermal efficiency about 60% based on heat recovered, the R2E2 project will meet NEW

Water's goal of producing electricity in the most efficient way while maintaining autogenous combustion.

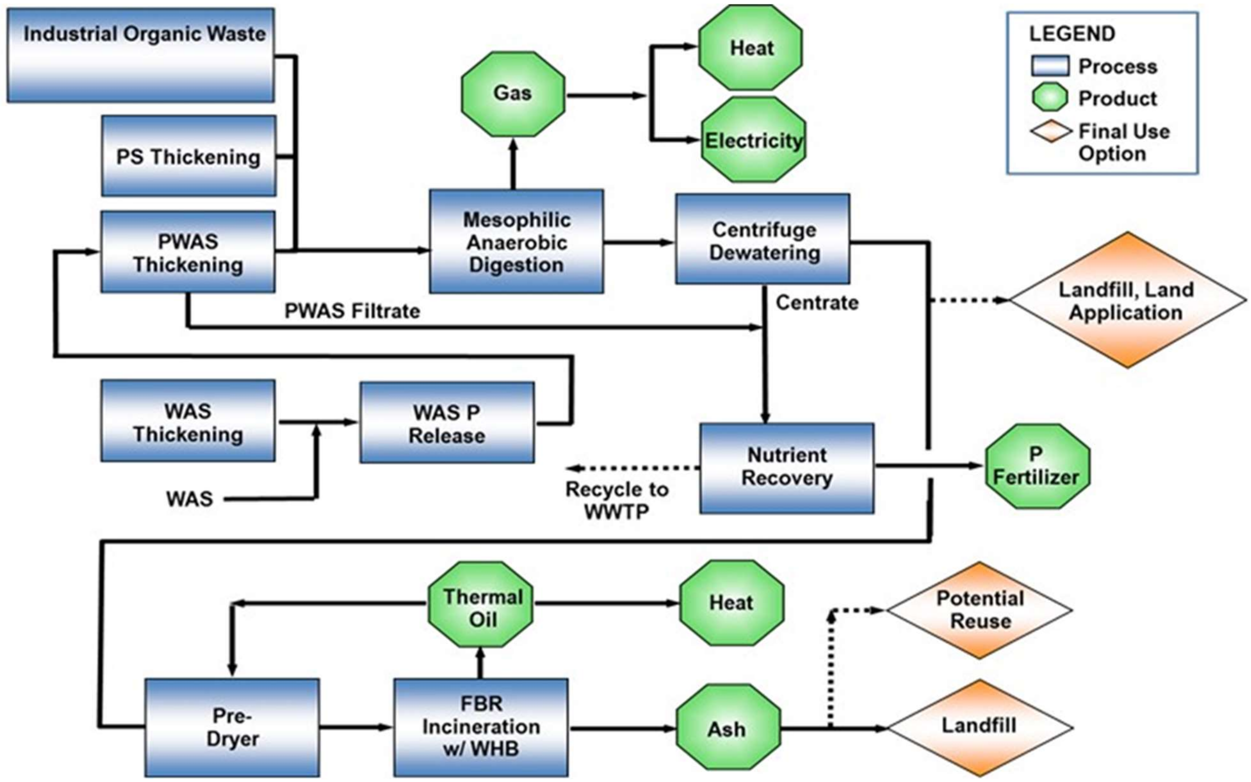

Figure 1 - R2E2 Process Schematic

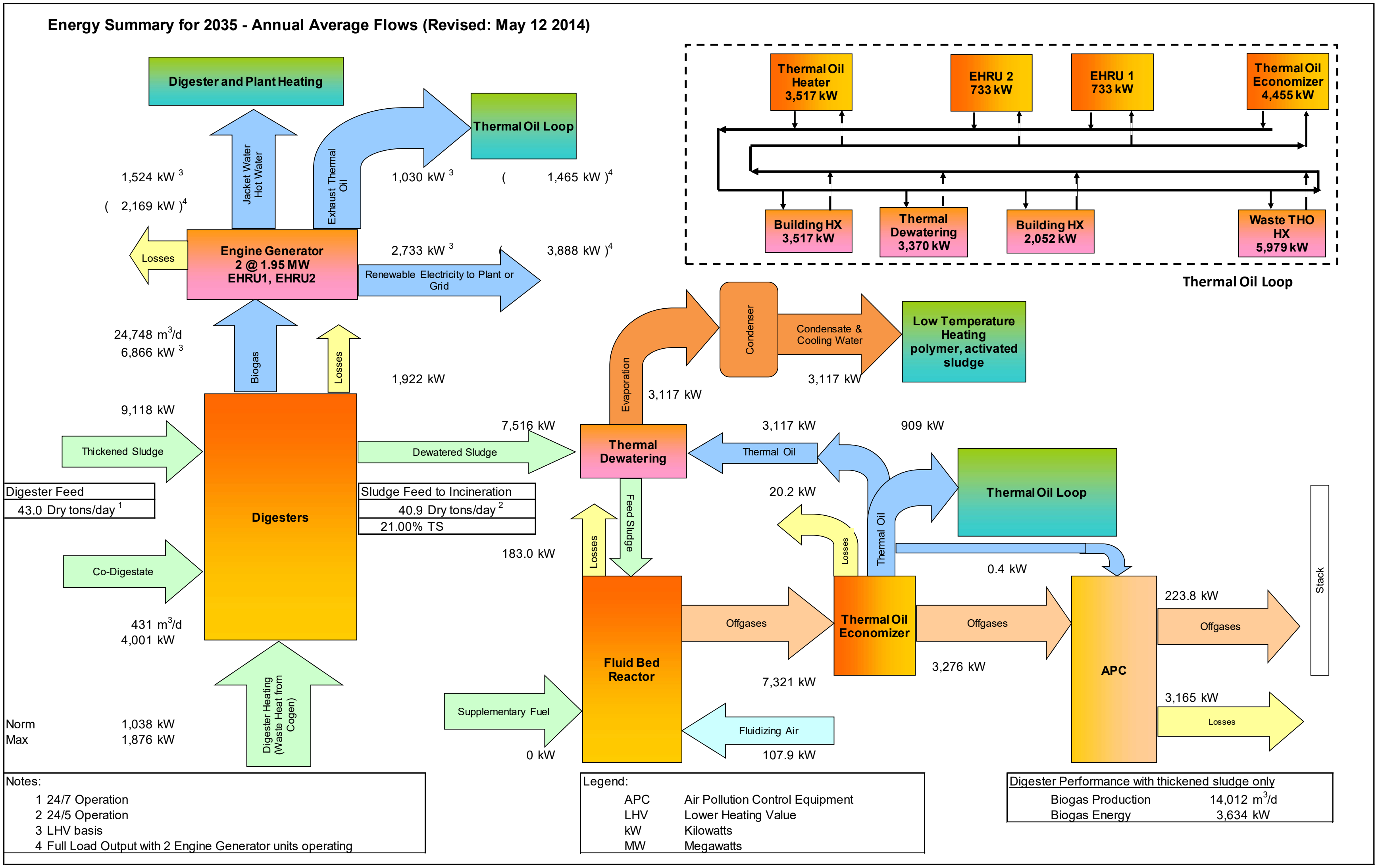

Figure 2 - R2E2 Energy Summary Schematic Diagram

START-UP AND ONGOING OPERATIONAL RESULTS

This section presents the anaerobic digestion (AD) start-up, biosolids characteristics, FBI stack emission testing, and the FBI performance testing results.

Anaerobic Digestion Start-up

Figures 3 through 6 show trends of various parameters for AD 1 and AD 2 during start-up and through mid-February 2019.

Figure 3 shows the daily volatile solids loading to both digesters and the biogas production. For AD 2, initial thickened sludge feed began in March 2018 and gradually increased, as the AD acclimated to anaerobic operation. The biogas production trend followed volatile solids feed. For AD 1, the initial thickened sludge feed began in November 2018 to the digested sludge seeded from AD 2. Because the reactor was seeded with organisms from AD 2 the production of biogas began almost immediately.

Figure 4 shows biogas quality, specifically methane, carbon dioxide, and hydrogen sulfide (H_2S) concentrations for both digesters. Methane content was approximately 60% for both digesters, with carbon dioxide at approximately 40%. For AD 2, initial H_2S concentrations spiked to 350 ppm during initial ramp-up but dropped to about 50 ppm. For AD 1, initial and current H_2S concentrations are about 50 ppm.

Figure 5 shows digested sludge solids concentrations for total and volatile solids, as well as, volatile solids reduction (VSR) for AD 2. The digested sludge concentration has stabilized at about 3.5%. VSR is about 45% to 50%.

Figure 6 shows the pH of digested sludge and feed sludge for both digesters. Digested sludge pH is between 7.25 and 7.5, while the thickened sludge feed pH is between 6.5 and 6.75.

Figure 3 - Volatile Solids Loading and Biogas Production

Figure 4 - Biogas Quality

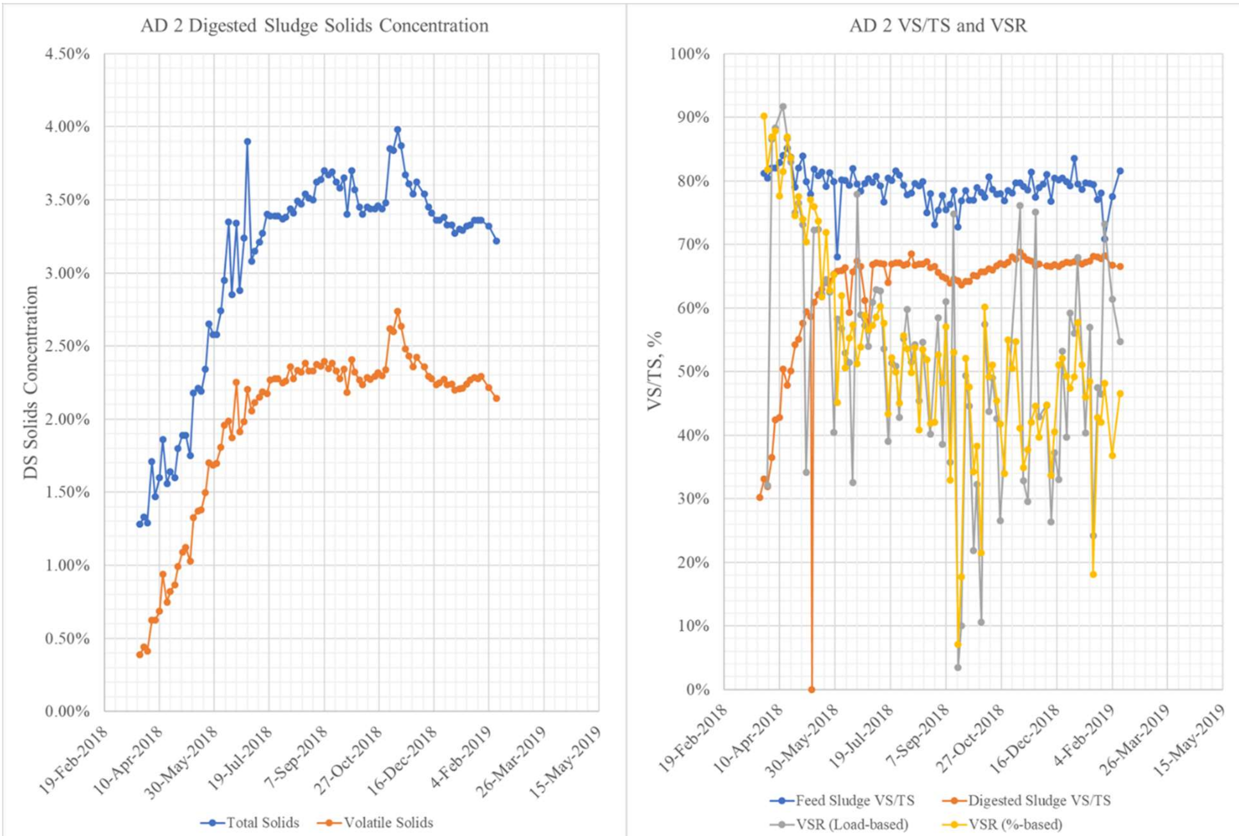

Figure 5 – Digested Sludge Concentrations and Volatile Solids Reduction

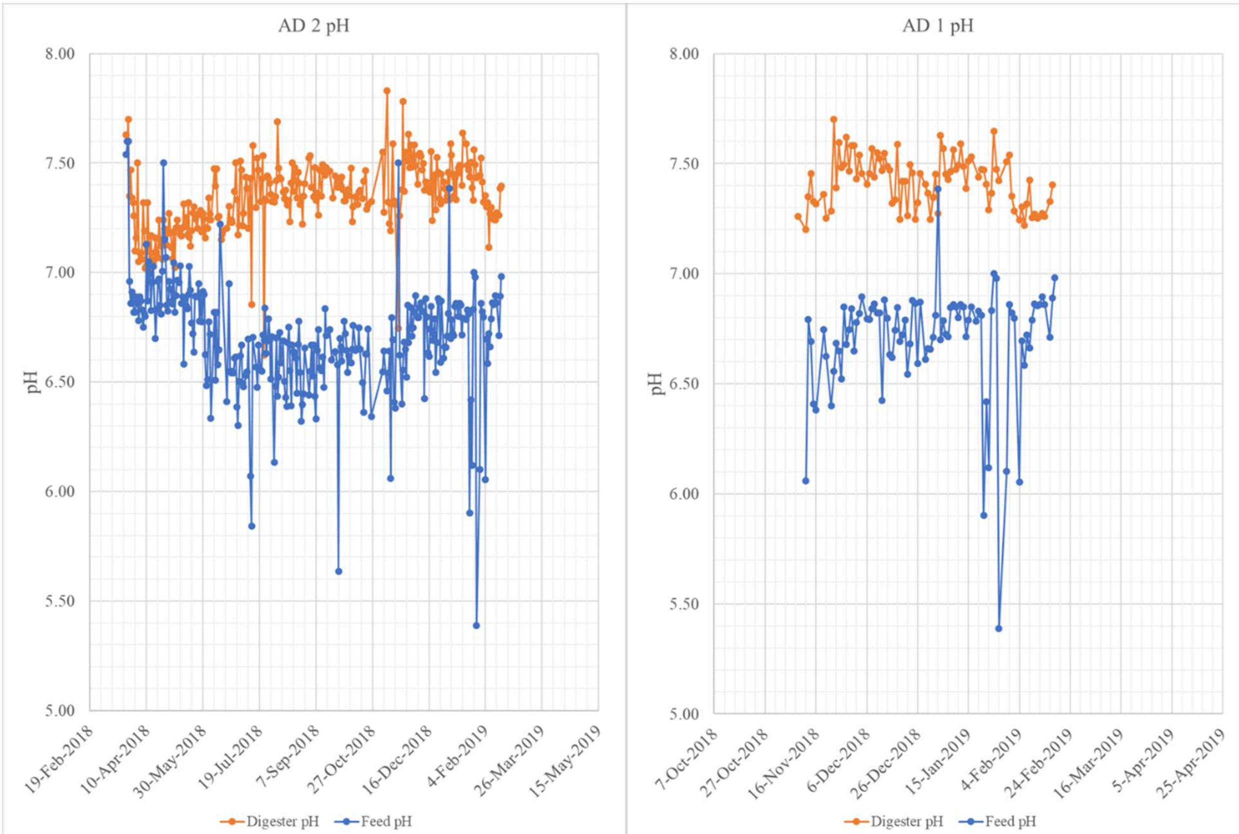

Figure 6 - Digester and Feed pH

Biosolids Characteristics

The FBI system is designed to incinerate 46.4 dry metric tons per day (dtpd) autogenously based on the primary design conditions in the procurement documents. Table 1 shows the primary design conditions, as well as the biosolids characteristics during the stack emission testing and performance testing.

Table 1- Biosolids Characteristics

Parameter	**Design**	**Stack Emission Test**	**Performance Test**
Dry Feed Rate	46.4 dtpd	42.5 dtpd	36.9 dtpd
Dry Solids	39%	36.2%	37.1%
Volatile Solids	64.9%	73.1%	67.1%
HHV Volatile Solids	24,423 kJ/kg	24,667 kJ/kg	22,644 kJ/kg
Ultimate Analysis – Moisture, Ash-Free			
Carbon	54.74%	56.54%	54.94%
Hydrogen	7.59%	7.15%	7.74%
Oxygen	28.45%	27.58%	27.56%
Nitrogen	7.93%	7.41%	7.74%
Sulfur	1.14%	1.35%	2.03%

Air Permitting Background Information

The R2E2 FBI system is permitted under 40 CFR Part 60 Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units; Final Rule (EPA 2011) as a new stationary source, under subpart LLLL. NEW Water was required to develop and submit to the EPA petitions for specific operating parameters, operating limits and averaging periods for ammonia injection to control oxides of nitrogen and the carbon adsorber for mercury control. New Water also needed to develop Site Specific Monitoring Plans (SSMP) for all air pollution control systems that will be used either for continuous parametric monitoring or continuous monitoring. During commissioning, it was determined that ammonia injection was not necessary to control oxides of nitrogen within permit limitations. Additionally, the petition to utilize a carbon adsorber for mercury control was accepted. Achieving these favorable outcomes with the EPA required close coordination with all stakeholders including: the design consultant, air permitting consultant, the Wisconsin Department of Natural Resources, the FBI system provider, the air pollution control equipment manufacturer, the carbon adsorber manufacturer, and NEW Water legal counsel, operations, engineering, and compliance staff.

FBI Stack Emission Testing

The initial performance test comprised three test runs with the FBI system loaded at not less than 85% of design loading rate (AIR 2018). Compliance was based on the average values of the tested parameters. Emission limits and emission results are presented below in Table 2 (NEW Water 2018).

FBI stack emission testing was conducted on October 17-18, 2018, in accordance with a Wisconsin DNR (Department of Natural Resources) approved Site-Specific Test Protocol (SSTP). All testing was conducted by Advanced Industrial Resources, Inc. (*AIR*) in accordance with approved USEPA Methods (i.e., 40 CFR 60 Appendix A, Methods 1, 2, 3A, 4, 5, 6C, 7E, 9, 10, 23, 26A, 29 and 202).

Table 2- FBI Stack Emission Test Results

Pollutant	Units	Average Measured	Allowable	% of Allowable	Regulatory basis
Particulate Matter (PM), filterable	mg/dscm @ 7% O_2	< 0.6	9.6	< 6%	60 LLLL
PM, filterable + Condensable (C)PM	lb/hour	0.10	0.61	17%	Permit
	lb/ton of sludge	0.06	1.3	4%	Permit
$PM_{2.5}$, filterable + CPM	lb/hour	0.10	0.55	19%	Permit
PM_{10}, filterable + CPM	lb/hour	0.10	0.61	17%	Permit
Sulfur Dioxide (SO_2)	mg/dscm @ 7% O_2	0.1	5.3	3%	60 LLLL
Oxides of Nitrogen (NO_x)	mg/dscm @ 7% O_2	12	30	40%	60 LLLL
Carbon Monoxide (CO)	mg/dscm @ 7% O_2	1.2	27	4%	60 LLLL
Hydrogen Chloride (HCl)	ppm @ 7% O_2	< 0.1	0.24	< 22%	60 LLLL
Dioxins / Furans	ng (TEQ) /dscm @ 7% O_2	< 0.0026	0.004	< 58%	60 LLLL
	ng (TMB) /dscm @ 7% O_2	< 0.003	0.013	< 20%	60 LLLL
Mercury (Hg)	mg/dscm @ 7% O_2	< 0.0002	0.0010	17%	60 LLLL
	lb/24-hour	< 0.0001	7.1	< 0.001%	Permit
Cadmium (Cd)	mg/dscm @ 7% O_2	< 0.00007	0.0011	< 6%	60 LLLL
Lead (Pb)	mg/dscm @ 7% O_2	0.00049	0.00062	79%	60 LLLL
Beryllium (Be)	lb/24-hour	< 0.00001	7.1	< 0.0001%	Permit
Visual emissions (opacity)	%	0.3%	20%	2%	Permit

FBI Performance Testing

FBI system performance testing was carried out on December 4, 5 and 6, 2018 (Suez, 2019). Table 3 summarizes FBI performance test results. It should be noted that all values in the table are in US customary engineering units.

Table 3 - FBI Performance Test Results

Performance Parameter	**Units**	**Design Guarantee**	**Test Result**
Cold start-up fuel consumption	mmBTU	112	103.1
Fuel oil consumption	mmBTU/dry ton	0	0.57
Operating power consumption	kWh/dry ton	356	315
Net usable energy in thermal oil system	mmBTU/dry ton	1.13	2.89
Absorbent consumption (activated carbon)	lb/dry ton	0.5	0.25
Caustic consumption	lb/dry ton	18.2	1.81
Ammonia consumption	lb/dry ton	30	0
Hot stand by fuel oil usage after 2 days (49 hours) of hot stand by out of every 7 days (168 hours)	mmBTU	18.13	14.5
Time to heat up the fluid bed reactor to be able to accept sludge (after hot standby)	hours	1.5	1.01

DISCUSSION

Anaerobic Digestion Start-up

After starting to feed sludge on March 23, the feed rate to AD 2 was slowly ramped up by maintaining a moderate specific volatile solids loading rate (SVSLR [lb VS/day/lb VS-inventory]). The maximum allowable SVSLR was planned to be 0.16, but the SVSLR was normally maintained at 0.07-0.10. The tracking spreadsheet included a mass balance to calculate VS inventory over time. This served well as a guide during ramp up. The lab-measured digester VS values were used in calculating the actual VS inventory in the digester, and again assessing daily feed volume/VS load increases. In addition to monitoring the SVLSR, biogas quality (methane content), alkalinity, and pH were measured daily to identify any process excursions and adjust feeding accordingly. Due to various modifications of the FBI system, various other issues, and the initial thought that the existing multiple hearth incinerators could not handle more than 50% digested sludge in the feed, the AD was fed up to ~50% plant sludge load or less (typically for a shutdown of some sort), until the Multi-Hearth Furnaces (MHFs) could be shut down in early December 2018. There was therefore a lengthy period between stable operation of AD 2 and the seeding of AD 1. AD 1 and AD 2 are operating as expected and within the design parameters. The ADs are currently under loaded, as is expected, based on solids loading projections developed in the Solids Facility Plan (CH2M 2011). Current biogas production allows the CHP to generate about 1.5 MW continuously.

Biosolids Characteristics

The primary design conditions listed in Table 3 served as the basis of design for the FBI system. Biosolids characteristics were developed based on bench-scale testing and process modeling of digested sludge during design. Biosolids dry solids was based on Suez design for the dryer output/FBI input. Biosolids volatile higher heating values (HHV) and ultimate analysis of combustibles were based on multiple tests on GBF and DPF sludge. Testing of undigested sludge in February 2018 indicated that the volatile HHV was 95% of the primary design value. Several tests have been conducted between February 2018 and present. The results indicated that the volatile HHV of digested biosolids is about 92% of the primary design condition. The consequence of the lower volatile HHV for digested sludge is that the FBI cannot operate autogenously at the primary design condition. The reason is that the biosolids heat release at the primary design point was 30.56 GJ/h. The biosolids heat release with the characteristics measured during the performance test was 23.36 GJ/h. Using the design throughput of 46.4 dtpd, biosolids heat release would be 29.38 GJ/h.

Since the FBI system went into continuous operations, it has been determined that approximately 2.1 GJ/h to 3.2 GJ/h auxiliary heat input is required. Initially, this was provided using fuel oil injected through the bed injectors. However, it was determined that it was more economical to operate the preheat burners on natural gas and maintain the windbox temperature at about 200 ^{o}C. During initial operation, bed sand was discovered leaking into the windbox under normal operating conditions. it was determined that the air velocity through the tuyeres was not high enough to prevent sand leakage. When the preheat burner was turned on, sand leakage stopped. This temporary solution will continue until a permanent solution is implemented. One solution is to plug holes in the tuyeres to eliminate leakage. Another solution would be to operate the windbox at a higher temperature. As there is a deficit in heat release, due to the lower volatile HHV, preheating of the fluidizing air using a thermal oil heated heat exchanger would provide the heat deficit, as well as windbox temperature to prevent sand leakage. If this solution were adopted permanently, some holes in tuyeres would still have to be plugged.

FBI Stack Emission Testing

The initial stack test demonstrated that the FBI system complied with emission limits and standards for new source for fluidized bed incinerators. The FBI system also demonstrates compliance with other permit requirements imposed on NEW Water by Wisconsin DNR. All of the parameters, except for lead and dioxin/furan toxic equivalency (TEQ) basis, reported less than 50% of the allowable limit. Lead was measured at 79% of the allowable limit. While dioxins/furans measured 58% of the limit, NEW Water has the option of meeting the dioxin/furan limit using the total mass basis (TMB), which measured 20% of the limit. Either way, NEW Water should have no issues complying with the dioxin/furan limit. It should be noted that ammonia injection was not required to meet NOx emission limits. The main means of control for most pollutants is by the wet scrubber and wet electrostatic precipitator (WESP).

NEW Water is operating the system within the operating limits established during the initial stack performance test. NEW Water are required to perform stack testing annually, at which time operating limits will be confirmed. If changes are required, NEW Water must petition the EPA to change the operating limits

FBI Performance Testing

The results of the FBI performance test (Table 3) indicate that the FBI system complied with all consumption and energy guarantees, except for fuel oil use. These include fuel requirement for cold and hot starts, time to reheat after weekend shutdown, electricity consumption, energy available from thermal oil system and chemical and reagent consumption. As discussed in the biosolids characteristics section above, the FBI system may not operate autogenously due to the lower volatile HHV than the primary design condition. During the three performance test runs, the preheat burner operated, providing a windbox temperature of about 200 ^{o}C, representing reactor heat input equivalent to autogenous conditions. Figures 7, 8 and 9 show the impact of dry solids leaving the dryer on fuel consumption.

During the first performance test run, the dryer outlet biosolids dry solids averaged 39% and no fuel oil was required (Figure 7). During the second performance test run, the dryer outlet concentration averaged 36.6% and fuel oil was required in the last hour when the outlet concentration dropped to 36%. During the third performance test run, the dryer outlet concentration averaged 35.5% and fuel oil was required in the last two hours when the outlet concentration dropped below 35.5%. Above 35.5% fuel oil was not required. The foregoing illustrates that the FBI operation is sensitive to dry solids content, when volatile solids concentration and volatile HHV are constant.

The raw data from the performance tests were analyzed to determine dryer performance. The dryer demonstrated the ability to evaporate the design evaporation rate of 9,362 lb/hr of water, the ability to dry solids to 39% and the ability to meet the raw energy consumption of 1,450 Btu/lb of water evaporated during the performance test.

CONCLUSIONS

The R2E2 project is operating and performing successfully, following digester system, CHP and FBI system start-up and commissioning, during 2018. With modest amounts of high strength waste co-digestion, the digesters are producing biogas, which is being used to generate approximately 40% of the GBF's electricity usage. Stack and performance testing demonstrated that the FBI system is complying with the new source performance standards for new FBIs and meeting performance requirements that were guaranteed by the FBI System vendor, Suez. Biosolids characteristics have changed since design and this is impacting autogenous operation of the FBI system. Solutions are required to be implemented to address this.

The entire process train, except for struvite recovery is now operating continuously and, as the operators become intimately familiar with the new processes and equipment, operations will continue to improve to meet NEW Water's R2E2 Goals.

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