Photos courtesy of Jordan Irish and Irish Construction.

Above: Basement location of sludge pumps and heat exchangers.
Left: An aerial view of the completed IBES.

An Integrated Biomass to Energy System

Sandra Diorka, Tom Grant, and Curt Christeson

The Delhi Charter Township, Michigan, Publicly Owned Treatment Works is a conventional activated sludge treatment plant including raw sewage maceration, grit removal/classification, primary clarification, fine bubble aeration, secondary clarification, denitrification, disinfection, effluent polishing, and dechlorination, with treated effluent discharge to the Grand River, which discharges to Lake Michigan approximately 100 miles to the west.

Prior to the Integrated Biomass to Energy System (IBES) project, mesophilic anaerobic sludge digestion (meeting Class B criteria) was used for sludge stabilization before storage and ultimate application to farmland. The township is located just south of the city of Lansing with a population equivalent of 22,000 people connected to the treatment works.

The current average daily flow to the treatment works is 2.7 million gallons per day (mgd), and the design capacity of the plant is 4.5 mgd. The current average sludge produced is 11,400 gallons per day (gpd) at 4 percent total solids and 81 percent volatile solids.

In a comprehensive master plan of the treatment works performed in 2004, it was found that the existing anaerobic digestion system was able to process only about 1.97 mgd flow and was being overloaded. The existing digestion system was between 30 and 46 years old, mixing was marginal, various equipment items were in need of replacement, the integrity of the tanks and covers were questionable, and the system had reached the end of its useful life.

Originally the township considered rehabilitating the existing digestion system to meet the short-term needs for projected growth. During the project evaluation phase, the decision was made to use State Revolving Fund monies available through the state of Michigan to finance the project at an interest rate of 1.625 percent.

A requirement of the State Revolving Fund program is that the facilities to be constructed be sized to meet the 20-year projected flows and loadings. This meant the digestion system would need to be expanded along with rehabilitation of the existing system.

With this project, the township emphasized the ability to produce Class A biosolids and to generate electricity from the biogas produced.

Integrated Biomass to Energy System (IBES) Process Description

IBES is the first system of its kind in the world, developed by HESCO of Warren Michigan. The system integrates a two-phase anaerobic digestion system (2PAD) manufactured by Infilco Degremont Inc. (IDI) that produces Class A biosolids with a combined heat and power system that creates electricity energy through the use of microturbines fueled by digester gas. It then uses the microturbine exhaust gas to pre-warm the boiler water used to heat the digesting sludge.

2PAD is a unique two-phase anaerobic digestion system that produces Class A biosolids which can be land applied without restrictions, in accordance with the U.S. Environmental Protection Agency's (EPA's) 40 CFR Part 503 regulations. The process separates the acid- and methane-forming digestion phases (acidogenesis and methanogenesis), increasing the efficiency of both, and combined with the high temperature, destroys the pathogens to below detectable limits.

A two-year pilot study confirmed the effectiveness of the 2PAD System to meet EPA requirements for Class A biosolids. The system has been granted "PFRP Conditional National Equivalency" by the EPA, as recommended by the Pathogen Equivalency Committee.

Combined heat and power includes two 30-kilowatt microturbines that create electricity using digester gas as a fuel. The electricity is used at the treatment works site and is enough to power the pumps and related equipment used in the IBES. A heat exchanger extracts a

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Sandra Diorka is director of public services for Delhi Charter Township, Michigan. Tom Grant is senior project engineer for the consulting engineering firm Hubbell, Roth & Clark Inc. in Grand Rapids, Michigan. Curt Christeson is a vice president in the firm's Central Florida office in Maitland. This article was presented as a technical paper at the 2010 Florida Water Resources Conference in May.

Digester gas room, microturbine gas compression, and scrubbing skid.

Thirty-kilowatt microturbines and gas-to-water heat exchanger.

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portion of the heat in the microturbine exhaust gas to pre-warm the boiler water loop, minimizing the use of the boiler when maintaining the temperatures required for anaerobic digestion.

2PAD is an intermittent draw-and-fill anaerobic digestion system. The first stage is thermophilic digestion occurring at a temperature of 131°F, and with a design solids residence time (SRT) of two days. The second stage is mesophilic digestion occurring at a temperature of 99°F, with a design SRT of 10 days. Pre-heating of the raw sludge, further heating of the thermophilic sludge, and heat maintenance of the mesophilic sludge occur through a hot water boiler system and several water-to-sludge heat exchangers.

A schematic of the primary elements of the 2PAD system is presented in Figure 1.

The 2PAD process is operated in a set of draw-and-fill cycles that can be set to occur between two and four times per day. The Delhi Publicly Owned Treatment Works system is set to operate with three cycles per day, each cycle lasting eight hours.

A chart showing the various steps of a cycle is presented in Figure 2.

Periodically raw sludge is pumped from the primary clarifier to the pre-feed sequencing tank, where it is held until being transferred through the 2PAD system as indicated below. Following is a description of one 2PAD cycle.

1a. Pre-feed sequencing tank sludge (one third of the daily sludge flow) is pumped to the feed sequencing tank. This sludge is pre-warmed to a temperature of about 78°F by a water to sludge heat exchanger.

1b. At the same time the pre-feed sequencing tank sludge is being pumped to the feed sequencing tank, thermophilic sludge is pumped to the mesophilic digester. This sludge is cooled from 131°F to about 99°F by the mate of the heat exchanger from step 1a. An additional "cooling" heat exchanger is provided to achieve the 99°F temperature required for Mesophilic digestion if required.

2. Upon completion of steps 1a and 1b, feed sequencing tank sludge is pumped to the thermophilic digester. A significant heat demand is placed on the thermophilic sludge as the cooler feed sequencing tank sludge is added to the thermophilic digester, so the thermophilic sludge is being recirculated continuously through a water-to-sludge heat exchanger to provide the heat required to achieve a thermophilic temperature of 131°F. Once the 131°F temperature is achieved, the sludge must be maintained at this temperature for a minimum of three hours to become Class A biosolids.

3. The last step of the cycle is pumping sludge from the mesophilic digester (one third of the daily sludge flow) so that there is volume available for the next batch of thermophilic sludge to be pumped to the mesophilic digester at the start of the next cycle, step 1b.

Here is a list of the IBES primary process components.

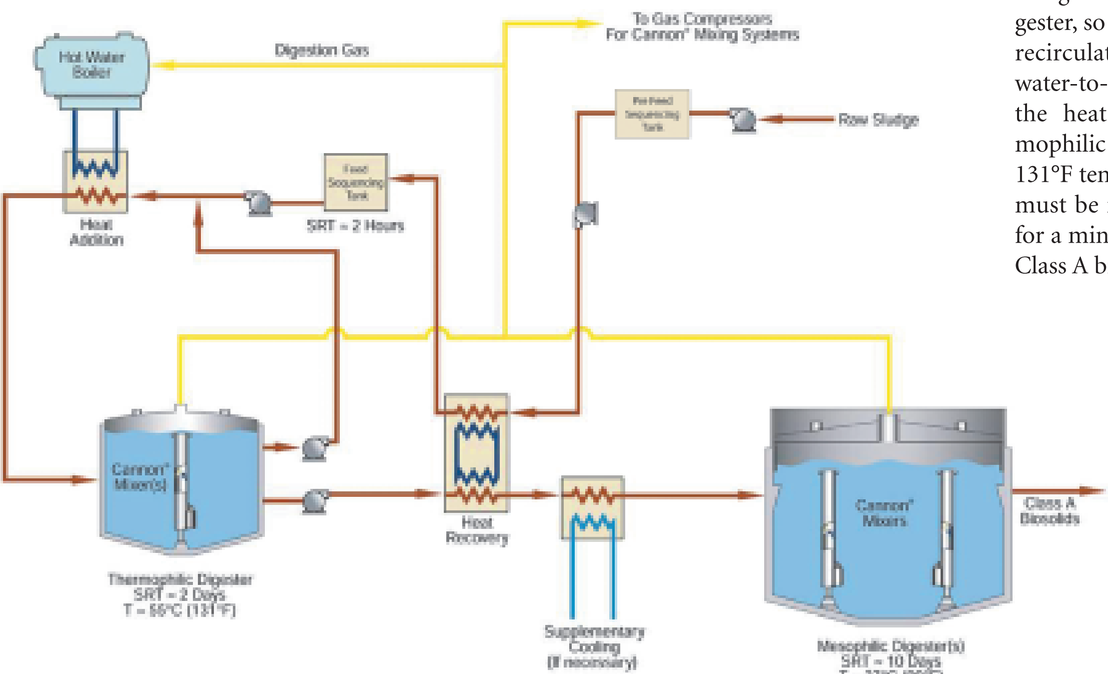

Figure 1 – 2PAD Schematic

- The pre-feed sequencing tank is a 23,000-gallon concrete, in-ground tank, 19 feet in diameter with a steel cover.
- The feed sequencing tank is a 23,000-gallon concrete, in-ground tank, 19 feet in diameter with a steel cover.
- Thermophilic Digesters No. 1 and No. 2 are each 45,000-gallon concrete, partially buried tanks, 19 feet in diameter with fixed steel covers.
- Mesophilic Digesters No. 1 and No. 2 are each 202,000-gallon, concrete, partially buried tanks, 40 feet in diameter with floating gas holder steel covers.
- Sludge mixing in the thermophilic and mesophilic digesters is provided through the use of IDI Cannon® gas mixers which use compressed digester gas to generate a bubble at the bottom of the cylindrical tube.
- The sludge transfer pumps are double disc diaphragm type pumping at about 60 gpm for a duration of 1.5 hours for each of three daily cycles.
- Sludge recirculation of the pre-feed sequencing tank, feed sequencing tank, and thermophilic digesters is provided with chopper pumps.
- The water loop boiler is 1 million BTUs per hour and can be fed with either digester gas or natural gas. Boiler inlet water temperature is designed to be at about 150°F, while boiler outlet water temperature is designed to be 180°F.
- Heat is transferred from the warm thermophilic sludge (131°F) to the cool pre-feed sequencing tank sludge (45° to 75°F) via two separate tube-in-shell, water-to-sludge heat exchangers. A water recirculation loop exclusive between only these two heat exchangers is used to achieve this heat transfer.
- The sludge within each thermophilic digester is warmed and maintained at 131°F by the use of individual tube-in-shell heat exchangers.
- The sludge within each mesophilic digester is maintained at 99°F by heating jackets located on the outside of each of the three Cannon® mixers located each digester.
- As required, thermophilic sludge is further cooled as necessary to maintain the mesophilic digester less than 100 °F.
- Digester gas is used as a fuel for two, 30-kilowatt microturbines to create electricity. The digester gas is pressurized and scrubbed of siloxanes and moisture prior to entering the microturbines as fuel.
- The approximate 530°F microturbine exhaust gas is used in a gas-to-water finned tube heat exchanger to raise the boiler inlet water temperature by up to 16°F. With both microturbines operating, the heat exchanger adds up to 250,000 BTUs per hour to the boiler water loop.

Figure 2 – 2PAD Cycle Chart

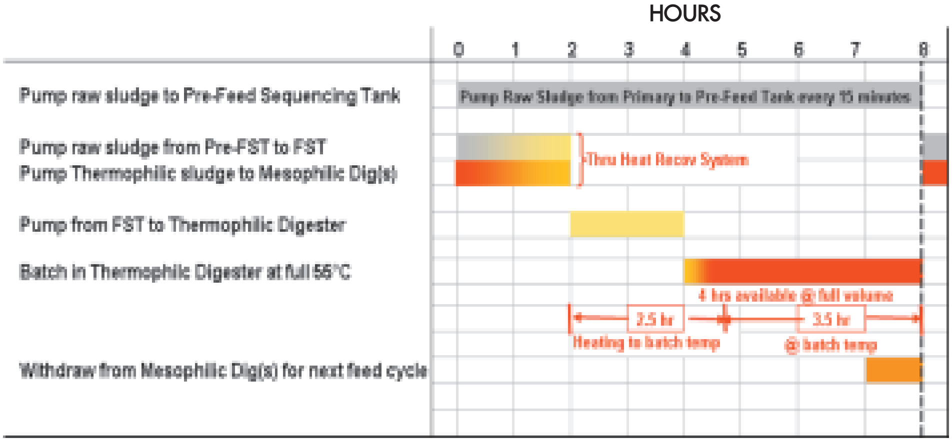

Table 1: Raw Sludge Loading Characteristics, Former Anaerobic Digestion to IBES

	Volume (gpd)	Total Solids (%)	Volatile Solids (%)	pH	Dry Tons
Former System	12,000	3.8	81.5	6.0	1.8
IBES	11,400	4.0	81.3	6.0	1.9

Design Engineering

Parts of the IBES process design was provided to Hubbell, Roth & Clark by HESCO via several schematic drawings, detailed equipment drawings, and specifications. The firm used this information to design and lay out the various tanks, building, pumps, piping, site work, electrical power, and related items.

The process design plans were developed using 3D Pipe, a three-dimensional autocad-compatible program. The IBES process included over four miles of sludge, digester gas, final effluent water, and non-potable water piping. The use of 3D Pipe prevented interference conflicts with pipe and other equipment items comprising the system. The site, building, and all process-related equipment and piping were laid out using this three-dimensional program, allowing the design team to design and view the system orthographically to scale.

Construction

Groundbreaking occurred in October 2007, and the construction was continuous until start-up beginning in May 2009.

Operation

Start-up of the new 2PAD process was conducted according to a plan developed by Delhi and IDI. The start-up involved using the existing mesophilic digestion system sludge as seed for the new 2PAD system. Through various transfers of primary and secondary sludge from the existing system to the new 2PAD system, start-up proceeded in a timely manner and was completed within about two months of beginning.

Both of the new thermophilic and mesophilic digesters were in service and operating at design temperatures by June 2009. The combined heat and power system (microturbines and gas-to-water heat exchanger) start-up occurred in July 2009.

The operation of the IBES process is controlled by two main control panels—one dedicated to the combined heat and power system, and the second handling the 2PAD system and also interfacing with the combined heat and power system panel. Normally, system control is automated with the exception of periodic checking of the various system components, manually emptying drip traps on the digester gas piping, etc. Through extensive SCADA, the operations staff can control and monitor the performance of IBES from their office or off-site.

Performance

A comparison of the former digestion system to the new IBES system was conducted from October 2008 through February 2009 for the former system and from October 2009 through February 2010 for the IBES system. The raw sludge loading characteristics are presented in Table 1.

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Table 2: Former and IBES Systems Performance Characteristics

	VS Reduction (%)	VS Destroyed (lb/day)	CF Gas per day	CF Gas per Lb VS Destroyed	% Solids of Digested Sludge
Former System	63	1,911	30,391	15.9	1.8
IBES	65	1,984	29,668	15.0	1.8

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Performance characteristics of both the former and IBES systems are presented in Table 2.

Several digester gas samples have been performed and analyzed for hydrogen sulfide and siloxanes since start-up of the IBES. These sample analyses have shown a higher concentration of both hydrogen sulfide and siloxanes than on two samples obtained from the former digesters. Siloxanes are removed through the gas scrubbing/compression system upstream of the microturbines. In a sample of the thermophilic digester gas stream, the concentration of sulfides and siloxanes was several times higher than that of the combined thermophilic and mesophilic gas streams. Since the thermophilic gas comprises only 10 to 15 percent of the combined gas stream, the option of removing the thermophilic gas from the combined stream is being investigated.

Since start-up of the 2PAD system, the heat exchanger between the pre-feed sequencing tank and the feed sequencing tank has had to be flushed and cleaned frequently because of plugging by macerated rags (the formation of "ropes") that plug the sludge flow tubes within the heat exchanger. A new sludge grinder was installed by the manufacturer just ahead of the heat exchanger to help alleviant the plugging by the rags, but the grinder did not help enough to justify its use.

Removal of the vast majority of screenable material at a headworks screen appears to be a critical component for the high-efficiency heat exchangers that are part of the 2PAD system. The addition of a new influent screening system is now under planning and design, which should reduce the maintenance of the heat exchanger and improve the efficiency of the solids digestion system.

Conclusions

The system has been in operation less than a year. The plant staff, design engineers, and manufacturers have experienced some start-up difficulties which were not unexpected with a new process such as this. As with any system, to properly monitor performance it is helpful to have metering and instrumentation in place. Lessons learned from this installation are that it would have been beneficial to have separate electrical and gas meters at the digester site to help determine the consumption or production of those utilities to help evaluate system efficiency.

Project negatives

- The supernatant quality and the dewaterability of the 2PAD sludge at this point is unexplainably poor.
- Gas production of the 2PAD system has not increased over the former mesophilic digestion system. The expectation was that gas production would increase.
- The thermophilic digester gas contains higher concentrations of hydrogen sulfide and siloxanes than the mesophilic digester. More design consideration should be given to better treatment of the gas or wasting the relatively small quantity of thermophilic gas to avoid treatment of that gas stream.

Project Positives

- The mixing of the 2PAD system is superior to the former mesophilic digestion system, allowing less future digester maintenance and cleaning and producing more efficient digestion by increasing total solids concentration.
- The 2PAD system uses less energy to achieve Class A biosolids than conventional thermophillic digestion because the 2PAD themophilic phase takes place in a smaller vessel; thus, there is less sludge to heat.
- Between July and November 2009, the microturbines operated at about 44 percent of their maximum, most efficient capacity of 60 kilowatts, saving about $44 per day in electrical costs. This savings equates to about 60 percent of the electrical costs of operating the IBES.
- Heat is recovered from the turbine electrical generators (theoretical recovery should be about 25 percent, but actual recovery has been less thus far).
- With the 2PAD system, the plant has saved about $11,000 worth of natural gas over the former digestion system.
- The system produces Class A solids for less O&M cost than the former digestion system produced Class B solids, primarily because of using digester gas in the boilers and the reuse of heat during solids transfer operations between the pre-sequencing tank and the thermophilic and mesophilic digesters.