Sustainability and the Water-Energy Nexus

Stephen McGrew

The water-energy nexus can be stated as "the production of thermoelectric and hydropower requires water, and the water utility industry requires power to treat, distribute, and collect the water/wastewater." Water utilities consume approximately 4 percent of the electrical power generated in the United States(1). Electric utilities use 196 bil gal per day (bgd) of water for thermoelectric power generation, a large portion of which may be for pass-through cooling. By comparison, public water suppliers only use 44 bgd of water(2). Thermoelectric power generation requires water to produce energy, and more importantly, it requires water for cooling. In 2015, thermoelectric power generation accounted for 86 percent of the U.S power supply(3).

There are significant challenges with both water and energy. The world has limited resources and a growing population. The population of the U.S. is estimated to increase by 27.6 percent, from 326.6 million in 2017 to 416.8 million in 2060(4). Climate change may cause sea level rise, degrading groundwater through salt water intrusion, and thereby increasing the use of energy-intensive reverse osmosis (RO) water treatment. Rapidly evolving technology, such as cars powered by lithium batteries that are charged from the electrical power grid, may increase electrical demand.

This article presents the use of reclaimed water as a sustainable source of water for thermoelectric power plant cooling. The second portion of this case study describes how Palm Beach County Water Utilities Dept. (PBCWUD) has met its goal of 10 percent energy reduction and 5 percent green power based on electricity used per customer.

Part 1: The Water-Energy Nexus for Thermoelectric Power Generation

Background

Water utilities can treat wastewater to provide reclaimed water to thermoelectric power plants, and partnerships can be formed to best utilize both water and energy in an optimum manner. Florida is a leader in the use of reclaimed water for power plant cooling. The FAC 62-610.668 allows the use of reclaimed water for cooling water applications.

The water-energy nexus demonstrates the interdependencies of water and energy, which may change how resources are allocated. An electrical utility may have access to high-quality source water that would be better used for potable water. Resources could be exchanged, providing a higher-quality source water for potable use and reclaimed water used for evaporation in power generation.

A U.S. Department of Energy (DOE) power plant water usage and loss study found the raw water usage for natural gas combined-cycle power plants to be 283 gal/megawatts per hour (MWh)(6). To produce and pump water or reclaimed water also requires energy and is a part of the water-energy nexus.

Reclaimed water is a sustainable water source for use in production of thermoelectric power. Reclaimed water for power-plant cooling is a beneficial use and provides a base load demand for water utilities that is not weather-dependent, as compared to reclaimed water use for irrigation of green spaces. The increasing demand for electricity in the U.S. may result in greater use of reclaimed water for cooling water applications. As fresh water resources become scarcer, the power industry can minimize risk through the use of reclaimed water.

Stephen McGrew, P.E., PMP, DBIA, is manager of plant design with Palm Beach County Water Utilities Dept.

Reclaimed water presents a number of operational risks and challenges related to the propensity for elevated and variable concentrations of phosphate, ammonia, organics, chlorine, and select metals. In particular, the phosphate concentration is a key factor that can dictate process requirements and operational parameters of the cooling water system, in large part due to its tendency to form scaling species, such as calcium phosphate(7). A 2007 study for DOE, "Use of Reclaimed Water for Power Plant Cooling," provides reclaimed guidelines for cooling tower recirculating water and summarizes regulatory requirements for various states(8).

Green power, such as wind and solar, while not requiring water to generate power, is based upon natural earth cycles rather than customer demand. Water utilities can help take advantage of the excess power generation to treat and store water to help balance the diurnal electrical power generation and demand curves. Electrical-generating utilities may adjust rates to provide financial incentives for time of use by water utilities.

Water and wastewater utilities must provide continuous service, and therefore have

Figure 1. Water Treatment Plant No. 2 Lime Softener

Figure 2. Water Treatment Plant No. 8 Anion Exchange Vessels

Figure 3. Reverse Osmosis Energy Recovery Device

Figure 4. Southern Region Water Reclamation Facility Biogas Generator Enclosure

backup power generation, such as diesel or gas emergency generators. Electrical utilities can provide incentives for demand reduction and peak shaving for large power users; examples are the commercial industrial load control rate (CILC) and the commercial demand rate (CDR) implemented by Florida Power and Light (FPL) and utilized by PBCWUD, which save approximately $750,000 per year. These interruptible rates have helped reduce the amount of electrical power generation capacity, thereby saving capital cost for building larger power plants or from purchasing power at high rates from adjacent electric utilities.

Part 2: The Water-Energy Nexus for Palm Beach County Water Utilities Dept.

In 2011, PBCWUD established a goal of 10 percent energy conservation and 5 percent alternative green energy. Energy conservation projects include:

- Replacing two aging ozone treatment processes with an anion exchange.
- Adding energy recovery on a RO membrane treatment facility.
- Pump replacement and increased use of variable frequency drives.
- Aeration improvements at the Southern Region Water Reclamation Facility (SRWRF).
- Nanofiltration membrane replacement at two water treatment plants to lower feed pressures.
- Air conditioning and lighting improvements.
- Alternative green power generation that includes a 165-kilowatt (kW) solar panel system and two 375-kW biogas generators.

Anion Exchange

The PBCWUD has replaced its 900-pounds-per-day (lb/d) air feed ozone system at Water Treatment Plant No. 2 (WTP 2), which was used for color removal, with a fluidized bed anion exchange system. Construction of the 16.4-mil-gal-per-day (mgd) MIEX® high-rate treatment system was completed in 2012 by John J. Kirlin LLC. The MIEX is a patented magnetic ion exchange process developed by IXOM (formerly Orica WaterCare). The MIEX anionic exchange process is a low-energy green technology and partially removes dissolved organic carbon (DOC). Carollo Engineers designed the WTP 2 MIEX system, which is the largest installation in the U.S. and the second largest in the world.

The resin is mixed with the raw untreated water in a covered basin. The resin has a large particle surface area and magnetized iron that allow the resin to flocculate into larger particles as it rises, and the mixing shearing force is reduced. As the particles combine, they become heavier and fall back down into the mixer. The treated water flows upward through tube settlers to minimize resin loss. The anionic exchange system produces much higher-quality water compared to air feed ozone treatment, and it reduced both chemical usage and energy consumption.

Flushing of the distribution system was substantially reduced after the MIEX treatment was initiated. A planned rechlorination facility was no longer necessary, as the distribution residuals were stabilized. The disinfection byproducts, trihalomethanes (THMs), and haloacetic acids (HAAs), were also significantly reduced.

Water Treatment Plant No. 8 (WTP 8) has a 30-mgd capacity. There are two separate treatment trains: Train 1 has a capacity of 20 mgd and used lime softening, ozonation, and filtration; Train 2 has a capacity of 10 mgd with lime softening, filtration, and anion exchange. The aging energy intensive ozone system in Train 1 was replaced in 2017 with anion exchange after filtration using a fixed bed anion exchange system, manufactured by Tonka Water, to reduce DOC. The resin for both Trains 1 and 2 are the Tulsion A-72, strong base anion, type-1 macropourous-chloride form resin manufactured by Thermax. The WTP 8 Train 2 anion exchange system using the Thermax resin has been successfully used since 2008. The salt usage for WTP 8 fixed bed anion exchange is less than the WTP 2 Miex fluidized bed system, which influenced the decision to expand the fixed bed system at WTP 8.

Train 1 has 14 anion exchange vessels and Train 2 has seven vessels. A chloramine disinfectant residual of 2 mg/l is typically applied prior to the fixed bed anion exchange vessels to prevent biological growth, as free chlorine can damage the resin beads. The WTP 8 will utilize free chlorine disinfection after the total organic carbon (TOC) is reduced through the anion exchange system, followed by ammonia, to combine with the chlorine prior to potable water storage and pumping.

Energy Recovery

Water Treatment Plant No. 11 (WTP 11) is a 10-mgd RO brackish water treatment plant. This facility is one of the largest inland brackish RO treatment facilities and is the sole water supply for the cities of Belle Glade, Pahokee, and South Bay. The WTP 11 became operational in April 2008, at a recovery ratio of 80 percent. The original design estimated that the Floridan raw

Continued on page 10

Continued from page 9
water would degrade over 20 years to total dissolved solids (TDS) of 4,358 mg/l; unfortunately, the Floridan aquifer degraded much more rapidly to a TDS of 5,050 mg/l in only five years.

Due to feed pressure pumping limitations, the recovery ratio was dropped to 70 percent, requiring additional raw water and increasing the stress on the aquifer. An energy recovery device (ERD) was added to boost pressures into the second stage, and additional vessels were added to increase the membrane array from 38 to 40 vessels in stage 1 and from 19 to 20 vessels in stage 2. The ERD utilizes the wasted energy on the first-stage permeate to boost the feed pressures into stage 2, and acts similar to a turbocharger. The design-build team was Globaltech Inc. and Kimley-Horn & Associates Inc. The project was highly successful by restoring the RO recovery ratio to the original 80 percent, thereby reducing stress on the Floridan aquifer and reducing the energy consumption by 1000 kWh per mil gal (MG) of water produced[9].

Biogas-to-Energy Project

The SRWRF Digester Biogas Renewable Energy Project generates up to 20 percent of the facility's power requirements from the methane biogas that was previously flared and wasted. With completion of the biogas-to-energy project in 2013, all of the waste products generated at the facility are recycled, providing environmental stewardship (reclaimed water for irrigation and constructed wetlands, biosolids for fertilizer pellets, and biogas for energy production). This project was partially funded by DOE's Energy Efficiency and Conservation Block Grant (EECBG) program assistance agreement in the amount of $1.6 million, which covered a portion of the $3,529,000 project cost.

The SRWRF is a conventionally activated sludge domestic wastewater treatment facility, rated at 35 mgd, with a three-month average daily flow, and is currently operating at approximately 60 percent of the rated capacity. Sludge is collected in the existing clarifiers and transferred to three gravity belt thickeners, where the sludge is thickened to approximately 5 percent solids before being stabilized through anaerobic digestion.

There are two digester groups, each with three 65-ft diameter digesters; each group has two primary digesters with fixed covers and one secondary digester with a floating cover. These gas holder covers permit a cover travel of about 6 ft, and thus provide up to 20,000 ft^3 of biogas storage per secondary digester, with no other digester gas storage at the plant. The facility digesters receive an average of 86,000 gal of solids per day, with an average volatile solids concentration of 4.24 percent; this equates to an average of 30,000 lb/d of volatile solids fed into the digesters. On average, the volatile solids destruction for the SRWRF digesters was 15,800 lb/d, or 53 percent.

During design it was assumed that 15 ft^3 of gas is produced per pound of volatile solids. Gas samples were sent several times to determine the British thermal units (BTU) available for combustion, and to measure hydrogen sulfide and siloxanes. The digester heating requirements were subtracted from the gas production to determine the available gas flow for the renewable generators. The criteria for sizing of the generators focused on minimizing flaring and maximizing energy production, while considering seasonal flow variations. Two 375-kW internal combustion engines provided 96 percent gas utilization.

To maximize the use of the 460-volt (V) three-phase renewable generators, the power produced will be paralleled to the plant electrical grid. The power will be increased to 4,160V through the use of transformers and then paralleled using the existing Russ Electric switchgear. This electric power is used onsite, reducing the purchase of electric power that is produced using fossil fuels, and can generate an average of 455 kW of continuous electrical power, providing 20 percent of the required electrical power for the facility. To maximize the savings, the biogas generators are programmed to run at 100 percent capacity during the hours that FPL charges peak rates.

This waste-gas-to-energy recapture is an innovative project that demonstrates sustainable use at a wastewater treatment facility. It has potentially widespread application in similar wastewater treatment facilities, as well as other industrial facilities located throughout Florida; SRWRF is one of only a few facilities to reuse all three wastewater treatment process byproducts[10]. In addition, this project provides the facility with additional electrical generation capacity in the event of an emergency or during a disaster.

The utility values improvements that can increase positive public perception and embrace environmental stewardship. There are six objectives that were achieved in the biogas-to-energy project:

- Objective 1 - Complete the sustainability cycle at the facility by utilizing up to 100 percent of the biogas created at the facility.
- Objective 2 - Reduce energy supplied by the power grid.
- Objective 3 - Provide source green power to meet the utility's 5 percent alternative energy goal.
- Objective 4 - Increase electrical system flexibility.
- Objective 5 - Reduce greenhouse gas emissions.
- Objective 6 - Become a model for other utilities to recover and utilize biogas for energy production.

Figure 5. Southern Region Water Reclamation Facility Solar Panels

Solar Power

The installation of 162-kW ground-mounted solar panels was completed in fall 2013. The project was partially funded through a green energy stimulus grant. The solar panels, in conjunction with the digester biogas project, now exceed the utility goal of 5 percent alternative energy. The SRWRF has large buffer areas, with both grassy lawn areas and a tree canopy. The Suniva MVX Series 250W solar panels were placed in the grassy area along the plant access roadway and are visible from the Florida Turnpike. The individual solar panels connect to combiner panels where the direct current (DC) voltage is monitored through the plant supervisory control and data acquisition (SCADA) system using Modbus communication protocol.

The combiner panels connect to Solectria PVI 100-kW rectifiers, where the DC voltage is converted to 480-V, three-phase alternate current (AC) power, and the two rectifiers are then connected to the effluent pump building electrical gear. The effluent pump station has a base load energy usage greater than the solar power generation capacity. The electrical connection was made on the 480-V switchgear. Total yearly green energy production is estimated at 235,000 kWh, with an electrical savings of $20,000 per year.

Adding solar power to the treatment facility is an environmentally sound business practice. It's a relatively easy-to-implement project, in comparison with biogas-to-energy. Future expansion for the solar power may continue along the plant access roadway or mounted on the building roofs. There is ample space to expand the solar power from 162 to 500 kW when there are additional funding opportunities to further increase green energy and reduce the carbon footprint.

References

1. EPA website: https://www.epa.gov/sustainable-water-infrastructure/water-and-energy-efficiency-utilities-and-home.
2. EIA webpage: https://www.eia.gov/todayinenergy/detail.php?id=29952.
3. *The Wall Street Journal*, (2016) "Energy," Nov. 14, 2016, p R1.
4. U.S. Census Bureau website: https://www.census.gov/library/publications/2015/demo/p25-1143.html.
5. McGrew, S., and Tobon, M., (2012). "Design and Construction Challenges for a 36-Inch Diameter 18-Mile Reclaimed Water Pipeline." ASCE Pipelines 2012.
6. U.S. Department of Energy. "Power Plant Water Usage and Loss Study." August 2005, revised May 2007.
7. *Power* magazine webpage: http://www.powermag.com/using-reclaimed-water-power-plant-cooling-applications/?pagenum=1.
8. Argonne National Laboratory, ANL/EVS/R-07/3. "Use of Reclaimed Water for Power Plant Cooling for the US Department of Energy." August 2007.
9. Miller, M., Lee, J., and Black, N., (2015). "Energy Recovery Case Studies for Brackish Water Membrane Treatment Systems." *Florida Water Resources Journal*, March 2015.
10. McGrew, S., and Tobon, M., (2012). "Completing the Sustainability Cycle, Reclaimed Water, Pelletization, Biogas, and Solar Power." ASCE International Sustainability Conference, 2014.