Dania Beach Nanofiltration Water Plant Abstract

Faced with continuing growth and re-development, increased water demand, an aging lime softening plant, and issues meeting the disinfection by-product standard, the city of Dania Beach, FL, needed to upgrade its water treatment plant. Through an industry partnership, the university and the city's engineer collaborated with the city of Dania Beach to create the design for a new 2.0 mgd nanofiltration process to complement the city's existing 3.0 mgd conventional lime softening water treatment plant. This was no ordinary design. The students at the university asked the question, why can't we design a LEED certified "green" water treatment plant? Then the city got excited about the prospect too. So, the students developed an innovative membrane treatment plant concept that would be a high-performance facility in terms of energy efficiency, indoor air quality, solid waste management, and water use conservation. At the same time, the plant was designed to maximize system recovery while providing a high degree of operating flexibility. This was accomplished with a two-stage nanofiltration unit followed by a convertible third- and fourth-stage reverse osmosis unit to provide the city with the flexibility to meet their concentrate discharge limits when operating at industry-leading recoveries of up to 95 percent by operating in a four-stage configuration. The ability to operate at this previously unattainable higher recovery was tested by faculty and students. The senior civil engineering undergraduate students also provided preliminary design concepts that were used by the design professionals to actually construct this project, including LEED certification documents and specifications. On March 27, 2012, the new city of Dania Beach Nanofiltration Plant officially opened, and the project team submitted documentation to become the first LEED Gold-certified water treatment plant in the world.

Dania Beach Nanofiltration Water Plant Project Description

The water treatment plant that serves the city of Dania Beach, FL, and its 16,000 residents was developed between 1950 and 1975. Production from the city's drinking water well field is permit-limited due to the potential for salt water intrusion. To meet increasing demand, the city must purchase supplemental raw water from alternative sources. Currently, this raw water source is purchased from Broward County. The raw water is higher in disinfection byproduct precursors, color, and iron compared to the city's current raw water supplies, which means that the supplemental water's poor quality will adversely impact the operation of the current lime softening treatment facility. After evaluating the feasible options of buying water from other municipalities, the city determined that it would be less costly to increase capacity of their existing water treatment plant using Broward County's Biscayne aquifer source. But to meet operational and water quality goals, something needed to be done to address the water quality issues. The treatment process of choice was identified as nanofiltration, a membrane filtration process designed to remove hardness and metals from the water, along with the natural organic material that acts as a precursor to disinfection byproducts, like trihalomethanes.

Nanofiltration was chosen because it vastly improves water quality while permitting the city to expand the plant capacity through blending the lime softened and nanofiltered water to achieve a water quality that in nearly ideal from the city's perspective. Currently, membrane filtration system productivity in municipal water treatment plants is typically maintained between 50 to 90 percent, as water recovery (Sethi et al. 2006), depending upon raw water quality and system design. Designers, membrane manufacturers, and water treatment plants generally target the 50–90% water recovery range because of concerns related to: 1) efficiency limitations of current membranes and equipment; 2) concentrate management issues; 3) potential for increased or permanent fouling; 4) decrease in finished water quality; and 5) perceived potential cost increases due to more frequent membrane cleaning or replacement (Toro, et al, 2010).

Increases in recovery require increases in the driving force due to build-up in osmotic pressure, which will increase wear on the membrane and the pumping equipment (Bloetscher et al. 2006; Sethi et al. 2006). Hence, materials and construction costs will increase, and operation and maintenance costs will also be higher. Pushing the membranes to their limits will also potentially increase fouling or accumulation of dissolved solids on the membrane surface, which typically reduces membrane life, increases energy consumption, increases maintenance costs associated with more frequent cleaning cycles, and necessitates more extensive pretreatment (Lin et al. 2005, Ng 2004, Vrijenhoek et al. 2001, Kilduff et al. 2000).

In 2006, students were engaged to help the city with identifying solutions to its water supply infrastructure problems. Among the major issues were the condition of the water plant and loss of raw water supplies due to saltwater intrusion. The engineering solution was determined to be a high efficiency nanofiltration unit, with maximum product recovery. The city's engineer partnered with the university to perform the first ever pilot testing on the feasibility of achieving near zero liquid discharge on nanofiltration by pushing the membranes to 95+% recovery. One drawback to ultra high efficiency nanofiltration is the increased energy consumption. So the students investigated the possibility of designing a system that would meet the USGBC LEED-Gold criteria and maximize energy efficiency with high performance energy conservation strategies. This was tackled as part of the capstone design project for 8 undergraduate civil engineering majors.

The results of the pilot program and student design projects were used as the basis for the design-build project ultimately awarded to the engineer. The project was constructed over 24 months, being completed in November 2011, and provides a prototype for how students, faculty, professional engineers, and municipalities can work together to find innovative and cost-efficient solutions for tomorrow's infrastructure.

Collaboration of faculty, students, and licensed professional engineers to solve fouling issues

The city of Dania Beach, its engineer, and the university each included professional engineers that worked with students on this project. The first interaction between the students and professionals was during the pilot testing phase. The engineer and the university both own membrane skids suitable for pilot testing in the field. The two units in tandem provided a unique opportunity to test unprecedented recovery efficiencies (>90%). The engineer initiated a two-stage nanofiltration pilot plant configuration, recovering 85% of the raw water as permeate. The university students tested a third stage to boost the recovery to 90%. The students operated the university's pilot skid, monitored performance, and made necessary operational adjustments and/or repairs. The engineer and the university students worked with the city's operations engineer to ensure the systems were operating successfully. The 90% recovery was successful, so the engineer's skid was converted to a three-stage configuration, 90% recovery system; and the university skid was operated as a fourth stage to obtain up to 95% recovery. These levels have never been tested previously because fouling was thought to be a major barrier to this technology. However the students determined that while the first three stages required no pH adjustment, the fourth stage required a pH range of 6.1 to 6.3 to prevent premature fouling. The results of the university's pilot study results were used to develop the criteria for the professional services bid process.

A preliminary cost evaluation for the incorporation of a fourth stage and the impact of increasing the recovery up to 95% was found to be cost effective (Toro, 2007). If water recovery beyond 95% is implemented, it will reduce the typical concentrate volume by at least half and will increase the water use efficiency by 5%. The positive impact of this increase in water recovery will delay the need for alternative water supplies for 3–5 years.

Having crossed the technical limitation of the 90% recovery barrier, 8 students in the university's civil engineering capstone design class took on the preliminary design of this system as their capstone project. The threshold criteria to be met by the design were: limited purchase of power from the grid, USGBC LEED Gold certification, energy conservation, and onsite improvements in keeping with the needs of the city's engineering and operations staff. Over two semesters, the students created site plans, floor plans, and structural, geotechnical, stormwater, water, sewer, and onsite improvement plans. The city was already working with a faculty member (P.E.) as their project manager for the unique expansion. He was also the lead instructor for the capstone design class. The students found that off-grid power was difficult to create on the site without significant investments ($4.25 million for solar cells and mini-wind turbines to create the power needed to operate the plant). However in pursuing the power issue, they found that the plant could be readily certified under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED).

The students were able to discover a design approach to making this the first LEED Gold-certified water treatment facility in the world. LEED, which stands for Leadership in Energy and Environmental Design, is a process developed by the U.S. Green Building Council to highlight buildings that encompass the concepts of high-performance building into their process. In the LEED checklist, there are five categories that are used to evaluate buildings. The first is sustainable sites. The intent is to use existing disturbed sites as opposed to a virgin site. Another concept was to increase open green space on the site. The nanofiltration facility will be located on the same site as the current lime softening plant, which will be refurbished, upgraded, and made available to supplement the nanofiltered water. The improvements will integrate the new nanofiltration water treatment plant facilities with the current facilities and coordination of construction to minimize disruption to current activities. The final site plan proposed to increase the amount of perviousness on the site by reducing asphalt, removing unused structures, and installing pervious pavement. To encourage employee use of alternative transportation, spaces were provided for carpooling, low-emitting vehicles, and alternative fuel vehicles. A bus stop is already located at the boundary of the site, and showers and a bike rack were provided as well.

The second category is water efficiency. The facility will have a minimum recovery of 90%, which is greater than most conventional membrane systems in operation around the world today. The goal to achieve 95% recovery will improve water use efficiency by 10%. In addition, low-flow fixtures, such as high-efficiency toilets, waterless urinals, and low-flow faucets and showerheads, will be used. The project expects to save half the water use compared to a similar structure, or roughly 100,000 gallons per year, in addition to the increased water savings from process improvements (up to 36 million gallons per year). The city altered its irrigation ordinance to preclude the need to irrigate when Florida Friendly (drought tolerant) plants are used for landscaping.

The third category is energy and atmosphere. Since membrane filtration processes are power intensive, this was a major concern. However, the goal was set to reduce energy consumption by 30% over a similar building, in addition to membrane process improvements to maximize electrical power use. The strategic approach to reach this ambitious goal included energy conservation best management practices. For example, lighting retrofits to compact fluorescent bulbs and solar powered street lamps were specified, unnecessary lights were eliminated or turned off with automatic timers, and exterior solar lighting was used to reduce power costs. To increase energy efficiency of pumping within the water treatment process, variable frequency drives (VFDs) were installed. Energy recovery turbines on the permeate and concentrate streams were installed to recycle stranded energy from these high-pressure streams that would otherwise be lost in the process. The control building will have "cool roof" technology to deliver high solar reflectance, which has been found to lower the cooling load of the building significantly and lower the ceiling temperatures by 30 degrees. This roofing solution will improve occupant comfort, cut maintenance costs, increase the life cycle of the roof itself, and reduce urban heat island effects. Insulation was specified to increase energy efficiency, and the HVAC system for the building was designed to use high SEER efficiency units. Automatic energy management systems were installed to adjust temperatures inside the building. Interior energy use is expected to be reduced by 2 kWh/day, while the energy savings associated with the membrane process itself will be on the order of 20–30 kWh/day.

The fourth category is materials and resources. Recycled concrete and steel are available locally, and all materials met the buy-American clause. Many were purchased within 500 miles of the site, which reduces transportation costs and inherent carbon dioxide emissions. All concrete and steel removed from the site was recycled to the maximum extent possible, and construction debris was separated and recycled to minimize landfill impacts. The contractor was able to achieve over 95% material recycling and recovery, thereby reducing landfill costs.

The fifth category is indoor environmental quality, which is intended to reduce air pollution and increase occupant comfort. This was accomplished by specifying no or low VOC containing materials, paints, or construction adhesives. Smoking will be prohibited in and around the building. The HVAC system will be tuned to inside conditions, and occupancy levels are monitored with a sophisticated energy management system.

A final category for innovation in design included the novel water recovery systems incorporated into the membrane design, the potential to use the facility for educational purposes, and the fact that this would be the first LEED-certified process building at any water or wastewater facility in the world. The city engineer adopted this concept as a part of the bidding process. After receiving and evaluating proposals and conducting interviews with the prequalified bidders, the city awarded the project for design and construction of the 2.0 MGD nanofiltration process addition and associated improvements to the design-build team. In the final design, it is clearly seen how some of the student design concepts were incorporated into the actual construction. In addition, the facility has been submitted documentation to qualify as the first LEED Gold-certified water treatment plant in the world.

Benefit to public health, safety, and welfare

The basis of the project was to develop higher quality water for the residents of the city of Dania Beach using a sustainable and cost effective approach. Safe drinking water is a public health, safety, and welfare issue and is a basic service required for their customers. The city was relying heavily on Broward County water supplies, which could not be adequately treated with the current lime softening system. A new treatment process was needed. A hybrid nanofiltration with existing lime softening designed by a unique partnership of students and professionals resolved the troublesome water quality and cost concerns. The novel approach also reduced the chemical costs for both processes (less lime for hardness removal, less chemicals for stabilization of nanofiltered product water). An innovative membrane system design consisting of a three-stage nanofiltration membrane system with a convertible fourth stage reverse osmosis unit was developed by the students and engineering team to provide the city with the flexibility to operate at higher system recoveries to minimize costs for raw water supplies as well as concentrate disposal. The convertible fourth stage can either operate as a single stage to allow operation at 92 to 95 percent recovery to meet concentrate disposal requirements, or it can easily be reconfigured in a third and fourth stage 2:1 array to maximize system recovery to reduce operating costs, something never done before. This protects limited water supplies for the public and future benefit. The students showed the pathway to LEED certification; the design and construction process involving the engineer and the university students submitted documentation for enough points to become the first Gold-certified water plant process building in the world. Reduced power use and smaller ecological footprint are long-term benefits to the environment as well as the public, and the facility is set up to educate the community on water consumption and energy efficiency.

Multidiscipline and/or allied profession participation

Many parties were instrumental in the design and construction of the new water treatment facility for the city of Dania Beach. The university included 3 faculty members (two professional engineers and one E.I.), and 9 students in the process. The engineering firm included 4 professional engineers, plus construction personnel. The city team included one professional engineer and operations staff. Each brought a particular perspective and skill set to the project. Solving the pilot testing, concentrate minimization, and LEED issues are all problems that the students provided significant input to. The interaction between parties was positive, and the student concepts were by-and-large incorporated in the final result, leading to the success of the facility, which has won both the U.S. EPA award for sustainable infrastructure and a Florida Institute of Consulting Engineers design award.

Knowledge or skills gained

Having won the design/build bid, the construction team worked closely with faculty and students to integrate LEED features, develop the LEED templates, and incorporate original student concepts into the final design. The LEED certification process was administered by the university, so understanding green construction issues was one skill gained by the students during submittal of documentation for the LEED process.

Understanding the membrane filtration operation was a second major skill. The students were involved in the day-to-day pilot testing of the raw water supplies and development of the skid configuration for the final design. Few students, if any, ever have this type of opportunity during their coursework. Many of their recommendations were included in the final project.

The capstone projects required the students to implement skills learned in many classes as well as how to communicate with the on-site staff and engineers working on the project. The students developed presentation skills, planning skills, and writing abilities that they would never have learned in a conventional classroom. In addition, they applied their structural, geotechnical, and hydraulics engineering skills to the site and building design. The student design projects also included a significant portion devoted to reducing grid power by developing strategies to evaluate: 1) solar cells, 2) wind turbines, 3) pressure recovery, 4) fuel cells, and 5) mini-turbines using compressed methane (derived from a local landfill and piped to the facility). Based on evaluating these options, the first three seemed viable because the methane fuel needed to feed fuel cells and mini-turbines was not currently available to the site. For the solar cell option, virtually every surface of a building or a tank with a cover included solar panels. One solar panel vendor provided units with an estimated daily capacity of 385 kW/d, requiring a total of 415 solar panels on site. Another option evaluated 3-foot by 5-foot solar panels without onsite battery storage, utilizing an existing commercial buyback program to sell power back to the provider during the day in exchange for off-peak power at night. The utility also owned a 10,000 square foot parcel offsite. This site could be used to locate a solar field to generate 622 kW/d. The initial costs for these options were determined to add approximately 40% to the capital cost of the plant. However, by saving 236.5 kW per day, at current electricity prices, the present worth of power costs, at 6% interest per year over 20 years, generates nearly $3.5 million, which is about half of the capital cost of the project.

Standard wind turbines were determined to be impractical because of the low wind velocity field near the site (average 9 mph). However, the manufacturers of mini-wind turbines indicated that the lower wind speeds could be accommodated. It was determined that the mini-wind turbines had potential to provide 40 kW per day if hung on towers to increase the power generated per square foot of ground area. Pressure recovery was also evaluated at a concentrate pressure of 72 psi and flow of 48 gpm. Using a recommended micro direct current output turbine/generator, the unit was capable of recuperating 0.8 kW of power from the concentrate line. Such a small contribution was not deemed cost effective, so the city did not pursue any of the proposed on site power options due to first costs—the only issue the students recommended that was not pursued in the final construction of the project.

Conclusion

This project has provided an opportunity for students, faculty, and engineering professionals to collaborate on an innovative design/build process. From the perspective on the NCEES award, collaboration between students and professionals in the design and construction of a functioning water plant, incorporating the concepts and ideas students had toward making this a green building, is an experience that cannot be overstated. The project directly benefits the public health, safety, and welfare by providing safe drinking water, provides a multidisciplinary cooperation between water treatment professionals, engineers of various types, architects, and managers to develop knowledge and skills that can only be gained outside the classroom.

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