Purified Water Production: A Research and Development Plant Operator's Perspective

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Introduction and Background

Interest in water reuse technologies has been growing in recent years as the demand for potable water approaches the limit of conventional water supplies. In northeast Florida, the Floridan aquifer is the primary water supply for nearly 337,000 residents of the greater Jacksonville area, served by JEA. It's anticipated by JEA that potable water demands will continue to increase, necessitating consideration of alternative and sustainable water supplies. As a result, JEA has taken a proactive approach by launching a water purification program to evaluate potable reuse as an alternative water supply.

The water purification program includes research and development (R&D) testing, demonstration, and planned full-scale implementation. The primary objective of the R&D phase of the program was to collect trusted technical data through rigorous pilot testing to observe and compare process performance and purified water quality of the two industry-leading treatment trains for potable reuse.

This article describes the daily operations and maintenance (O&M) activities, water quality testing protocol, equipment troubleshooting, and lessons learned during R&D testing. Operational performance and water quality results are not the focus here and have been presented in other papers and articles on the R&D testing portion of the project.

The JEA R&D testing was the first in Florida evaluating the two leading treatment trains side by side with two drastically different source waters. One source water was from a more traditional municipal water reclamation facility (WRF) primarily consisting of residential customers and the other was from a WRF with significant industrial sources in the collection system. As a result, JEA gained a better understanding of each treatment train's robustness by observing how the leading treatment trains performed over these widely varying conditions.

The first train was equipped with ultrafiltration (UF) followed by low-pressure reverse osmosis (LPRO) and an advanced oxidation process (AOP), or UF-LPRO-AOP.

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The second train included flocculation-sedimentation, then ozonation, followed by biologically active filtration (BAF) and AOP, or Ozone-BAF-AOP. Figure 1 presents a process flow diagram depicting both treatment trains. To provide a true side-by-side comparison, these two systems were operated in parallel at the two different JEA WRFs for approximately five months each.

The next step in the water purification program will utilize the treatment train selected from the results of the R&D testing and implement this treatment approach for a demonstration facility with a treatment capacity up to 1 mil gal per day (mgd). The purpose of the demonstration facility will be to showcase the advanced water purification technologies, while amassing a considerable foundation of trusted technical data. Water quality data are essential for demonstrating the safety of the purified water to the public and to regulators. Operational data from the demonstration facility will also inform a more-efficient design for a full-scale facility. The demonstration facility will be fully expandable to full-scale implementation, which for planning purposes is approximately 10 mgd of purified water. The actual capacity of the full-scale facility will depend on the future need for the purified water.

Contracting with CDM Smith, JEA began a "turn-key" program for the R&D testing where, working collaboratively with JEA, CDM Smith selected and procured the equipment, developed the R&D testing and safety protocol, provided all O&M services, and prepared all applicable reports. The R&D plant was operated continuously and members of the consultant team were onsite daily.

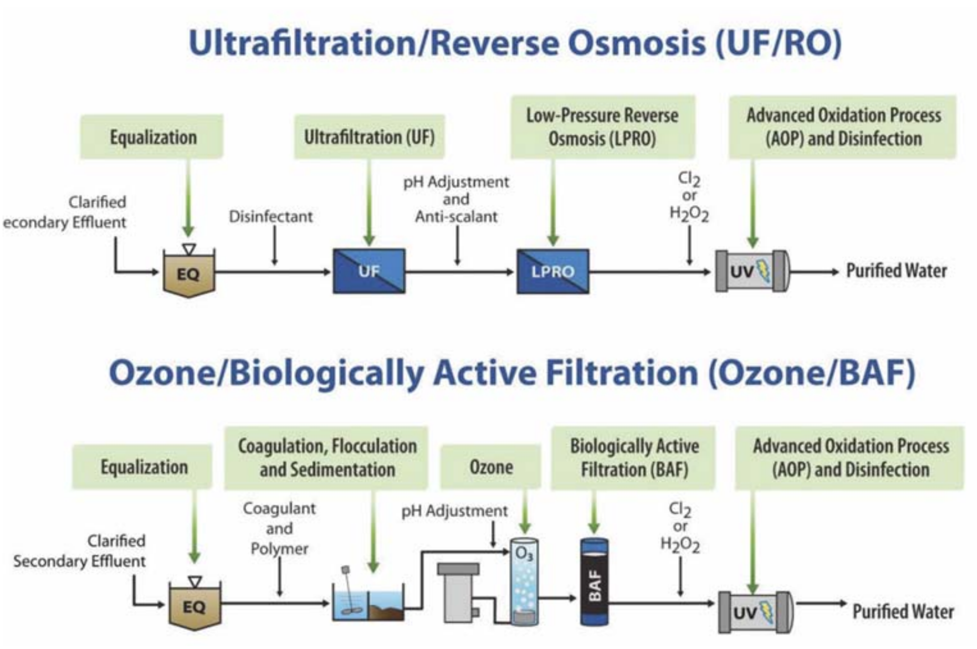

Figure 1. Research and development was conducted for two different water purification process systems.

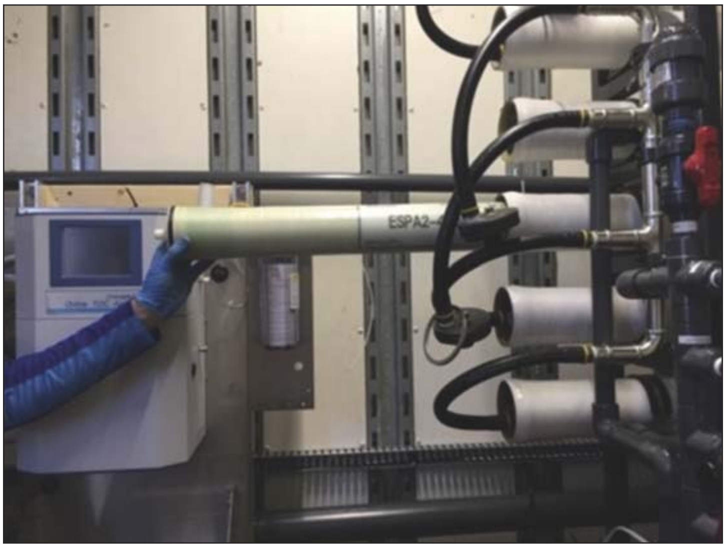

Figure 2. During start-up of the UF-RO system, new RO elements were installed, as well as an inline total organic carbon (TOC) analyzer. Inline TOC analyzers are not widely used, and this innovative instrument helped operators monitor treatment performance in real time.

Figure 3. Flocculation-sedimentation was used as a pretreatment step for the Ozone-BAF system. Shown is the sedimentation basin, along with the chemical storage metering pumps and operator interface panels.

Research and Development Testing Objectives

While the focus of this article is specifically on R&D plant operations, the overall primary objectives of the R&D testing were as follows:

- Characterize the secondary treated clarified effluent, prior to ultraviolet (UV) disinfection, at the Buckman and Southwest WRFs. This water was used as the source water for the R&D treatment trains.
- Identify a single-treatment process train system (either UF-LPRO-AOP or Ozone-BAF-AOP) for subsequent demonstration and implementation. This determination would be based on treatment performance, capital and O&M costs, waste management, ease of permitting, and reliability/robustness.
- Determine appropriate design criteria and operational parameters for the demonstration facility in order to develop a building layout, capital cost estimate, and O&M cost estimate for the demonstration facility.
- Develop a comprehensive public outreach plan to clearly explain the treatment processes and safeguards for public health, and provide consistent, readily available information to the community.

Research and Development Plant Equipment

This section provides information related to the R&D test equipment employed at the Southwest and Buckman WRFs. The R&D equipment for the two treatment alternatives was procured from various vendors, and the selection was generally made using performance-based specifications. Another criteria for equipment selection was treatment flexibility, not only for varying source water quality, but also for additional variables that are stated, which helped provide detailed costs and a clear direction for demonstration testing. The following subsections provide general information related to the water purification equipment utilized throughout the R&D testing.

Ultrafiltration and Low-Pressure Reverse Osmosis

The UF system served as the first unit process within the UF-LPRO-AOP system and consisted of the Spectrum Ultrafiltration Pilot Plant as manufactured by Wigen Water Technologies. The UF process consisted of two parallel UF modules. Following the UF process, the UF filtrate was combined into an equalization tank and conveyed to the LPRO system for further purification. A photo of the LPRO system is shown in Figure 2 (the photo was taken during start-up when the elements were being installed). This system, also provided by Wigen Water Technologies, was configured in a 2:2:1:1 array with a total of eighteen 4-in.-diameter elements. Individual process variables evaluated as part of R&D testing for the UF-LPRO process included a UF module manufacturer, UF flux rate, and LPRO flux rate.

Ozonation and Biologically Active Filtration

A pretreatment step, consisting of a coagulation, flocculation, and sedimentation system, was used prior to the Ozone-BAF-AOP system. Following sedimentation, settled water was conveyed to the ozonation system for further purification; following the ozonation process, ozonated water was conveyed to the BAF system. Three different media types and two different column configurations were evaluated in the R&D testing. A picture taken inside the Ozone-BAF system (manufactured by Intuitech Inc.) is shown in Figure 3.

Individual process variables evaluated during R&D testing of the Ozone-BAF process included coagulation conditions (i.e., coagulant type, dose, settled water pH), sedimentation basin overflow rate, ozone dose-to-TOC ratio, BAF media type (anthracite, spent GAC, virgin GAC), BAF media configuration (parallel versus series), BAF surface loading rate, and empty bed contact time.

Advanced Oxidation

A common advanced oxidation system served as the final unit process for both processes. This system was manufactured by SUEZ. The UV dose, oxidant dose, and oxidant type (sodium hypochlorite versus hydrogen peroxide) were evaluated as part of the R&D testing.

Data Sources

Data that formed the basis of the process train evaluation originated from multiple sources, including online instruments, field measurements, and discrete sampling events. These data included both physical data (i.e., process flows, process pressures, etc.) and water quality data (i.e., turbidity, pH, conductivity,

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temperature, etc.). The UF-LPRO and Ozone-BAF systems were typically operated 24 hours a day, seven days a week, unless scheduled maintenance or unscheduled disruptions caused temporary shutdowns.

Online Instrumentation

Online instruments served a critical role throughout the R&D testing, allowing operators and engineers to remotely monitor the R&D plant data. On many individual unit processes, online instruments provided continuous monitoring of various process parameters via a digital display and internal data logging (i.e., temperature, conductivity, ozone transfer efficiency, process pressures, flow, tank levels, etc.) that enabled the automation of numerous system functions. These online instruments also provided excellent operational data for both physical operating parameters and select water quality parameters, including turbidity, conductivity, and TOC.

The R&D plant operators typically transferred data from online instruments into a master Excel spreadsheet once a week. The master spreadsheet for data management was developed by CDM Smith at the beginning of the project with preset plots, which helped operators and engineers quickly recognize anomalies in the operating data. With five months of testing planned for each WRF, the early effort of developing the spreadsheet and plots prior to receiving data was critical for making process decisions quickly and staying on schedule.

Raw data from the UF-LPRO system were stored in an online database and managed by the system manufacturer. Raw data from the Ozone-BAF system were stored on USBs, located inside the equipment panels onsite. Also, data stored by the inline TOC analyzers were copied to a flash drive, then uploaded into the master spreadsheet. While the process of transferring data was not particularly difficult in itself, ample time of approximately three to four hours each week was allotted to perform the data transfers, quality-check the data, and troubleshoot instruments as needed.

Field Measurements

Data obtained from online instruments were supplemented with data obtained from field measurements. Field-measured data included both physical operating parameters and water quality parameters. In some instances, field measurements were intended to verify information obtained from online instruments (i.e., conductivities, pH values, turbidity values, etc.). In other instances, field measurements were intended to generate new information, either to monitor the operation and performance of individual unit processes (i.e., dissolved oxygen concentrations, adenosine triphosphate [ATP] concentrations, TOC concentrations, etc.) or to minimize the potential for process interruptions (i.e., bulk chemical tank levels, differential pressure across basket strainers, etc.). Field-measured data associated with individual unit processes are summarized in Table 1. Physical operating data were collected daily, and field water quality analyses were typically conducted four times each week.

Routine Sampling Events

Routine sampling events were conducted on a weekly basis throughout the R&D testing to monitor the performance of individual unit processes, as well as the overall treatment process systems. Each of these routine sampling events involved the collection of over 350 discrete samples from various process streams, followed by their packaging and shipment to a certified analytical laboratory for subsequent analysis. Generally, performing routine sampling events required two R&D plant operators to be onsite for at least eight hours each. Additional follow-up with the laboratory was often required to coordinate sampling schedules and notify the laboratory of any changes in sampling protocol, if required.

Comprehensive Source and Purified Water Sampling Events

Comprehensive source water and purified water sampling events were conducted during the R&D testing to provide a holistic assessment of the R&D plant source water quality and purified water quality from each purification process.

Each of the periodic purified water sampling events involved the collection of discrete water samples from six specific locations within the process systems (R&D plant source water, UF-LPRO permeate, UF-LPRO-AOP purified water, UF-LPRO concentrate, Ozone-BAF treated water, and Ozone-BAF-AOP purified water). Typically, these sampling events required four operators to be onsite for at least six hours each. This testing protocol allowed for the direct comparison of the two treatment processes. Once collected, all samples were packaged and shipped to a certified analytical laboratory for subsequent analysis. In addition to primary and secondary drinking water standards, more than 250 currently unregulated constituents (i.e., terpenes and fragrances, pharmaceuticals, pesticides and herbicides, etc.) were investigated for each sampling event.

Operational Lessons Learned

This section focuses on the specific operational lessons learned over the 10-month R&D study. To accurately explain abnormalities in operating and water quality data, the importance of good recordkeeping should be emphasized throughout. Accurate documentation and written records were essential in determining the cause for equipment interruptions and assisted in identifying similar issues on other equipment. Close collaboration with WRF staff on scheduling and planned maintenance activities also helped overcome challenges encountered during potable reuse R&D testing.

Research and Development Plant Source Water Variability

The R&D testing was conducted over an approximately 10-month period. The largest fluctuations in R&D plant source water quality were related to temperature and seasonal variability. For example, atypical operating conditions at Southwest WRF arose from the proliferation of filamentous-bulking bacteria within the wastewater treatment process, as well as the subsequent actions implemented by the

Table 1. Field-Measured Data and Equipment Utilized

Parameter	Equipment (Method)	Unit Processes Monitored
pH, Temperature, ORP, Dissolved Oxygen (DO), Conductivity	YSI Model 3074	Ozone-BAF and UF-LPRO
Turbidity	Hach 2100Q Turbidimeter	Ozone-BAF and UF-LPRO
Ultraviolet (UV) 254	Hach DR 4000 (Method 10054)	Ozone-BAF and UF-LPRO
Iron	Hach DR 890 (Method 8008)	Ozone-BAF and UF-LPRO
Free Chlorine	Hach DR 890 (Method 8021)	Ozone-BAF-AOP and UF-LPRO-AOP
Total Chlorine	Hach DR 890 (Method 8167)	Ozone-BAF-AOP and UF-LPRO-AOP
Adenosine Triphosphate (ATP)	Luminultra Deposit and Surface Analysis Kit	Ozone-BAF
Peroxide Residual	CHEMetrics Hydrogen Peroxide ColorimetricTest Kit	AOP

Southwest WRF operations staff to remedy the situation (i.e., chlorination of the return activated sludge). Ultimately, the plant upset at the Southwest WRF and the lower coagulant dose being evaluated at the R&D plant during that time resulted in elevated values for several water quality parameters, including but not limited to, turbidity, TOC, and total nitrogen.

Variability in the source water characteristics was also observed during the R&D testing at Buckman WRF, which is JEA's largest treatment plant, with a permitted average capacity of 52.5 mgd. Loading conditions to the R&D plant varied on a daily basis, which is indicative of its commercial and industrial customer base.

Troubleshooting Equipment

The R&D plant typically operated 24 hours a day, seven days a week. Troubleshooting equipment issues and performing preventative maintenance were key aspects in ensuring satisfactory operation of the R&D plant by reducing the frequency of unplanned shutdown events.

This section highlights the normal maintenance duties and specific equipment issues encountered by the R&D plant operators. Most, if not all, of these equipment issues were related to the challenges inherent with the modular, pilot-scale systems being tested. Full-scale water purification facilities include many additional design features (i.e., integrated alarms, supervisory control and data acquisition [SCADA], backup power, etc.) to avoid these issues and provide a reliable and robust treatment process.

Ultrafiltration and Low-Pressure Reverse Osmosis System

From an operational perspective, the UF-LPRO process generally provided consistent and reliable operation. While operational anomalies were experienced during R&D testing, these irregularities did not arise from inherent flaws or limitations of the UF-LPRO process itself. Operational abnormalities included programming issues, unplanned shutdown of chemical feed systems, unplanned power outages, etc., and are explained in more detail in the following section.

- *Programming and Controls* – In December 2017, while the R&D plant was operating at the Southwest WRF, an anomaly associated with the programming and controls of the LPRO pilot unit resulted in temporary overpressurization of the LPRO system. This overpressurization event displaced an O-ring that served as a barrier between the feed/concentrate and the permeate streams and damaged the membrane elements installed in the Stage 2 pressure vessels. The programming issue and alarm settings were corrected, a manual pressure relief valve was installed as a backup, and the displaced O-ring was replaced. Water quality data were closely monitored following the overpressure event, and it was decided that the event caused a slight compromise in the integrity of the Stage 2 elements, which were subsequently replaced
- *Power Outages* – The regularly scheduled generator testing conducted by WRF plant staff was generally well-coordinated with R&D plant operations and did not cause any unexpected challenges; however, unplanned power outages (i.e., short "blips" in power supply) would sometimes cause significant challenges, particularly for the UF-LPRO pilot system. For example, a power interruption could cause the breaker on the

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chemical feed pump system to trip, resulting in loss of chemical feed. Also, losing power would cause the online TOC analyzers to cycle off and on, and sometimes resulted in lost data.

Ozone-Biologically Active Filtration System

Generally, R&D plant operators focused their daily onsite efforts on the Ozone-BAF system. While this system was fully automated, it included more operationally complex unit processes and required more daily maintenance. The primary activities associated with maintaining the Ozone-BAF system are described.

- *Flocculation-Sedimentation Feed Pump* – The Ozone-BAF system was deliberately shut down approximately four times per week to clean the feed pump impeller to the flocculation-sedimentation system. Daily monitoring of the feed pump power output (0 to 100 percent) allowed operators to identify when the pump was getting clogged. The impeller was typically clogged with debris. An inline basket strainer was installed upstream of the equalization tank to help with this problem; however, it didn't significantly reduce cleaning frequency. Replacement of the feed pump with a pump that is more capable of pumping solids is advised for future projects of this nature.
- *Ferric Chloride Sludge Waste* – The sludge handling system was inspected daily for evidence of floc carryover and/or sludge buildup. The settled floc (sludge waste) was removed intermittently from the sedimentation basin and conveyed to a lift station, which pumped to the headworks of the WRF. The pilot equipment used was designed for typical conditions, and for this project, it was undersized for the coagulant dose required. To help prevent clogging of the sludge collection system, the highest-available sludge flow rate of approximately 1.4 gal per minute (gpm) was used; however, the hoses on the sludge collection system would clog periodically, causing a motor fault alarm and the system to shut down. In addition, due to the high ferric dosages used for this project, the sludge collection motor seal required periodic replacements (three times total), resulting in additional downtime.
- *Ozone Destruct Catalyst* – The ozone-laden off-gas from the ozone system flowed through off-gas piping and an ozone destruct catalyst to remove ozone. During hot-weather periods, the water would reach temperatures greater than 88°F. The resultant off-gas during the hot-weather periods was very humid and caused excessive condensation on the inside of the off-gas piping and destruct catalyst chamber, effectively reducing the life of the catalyst dramatically. This caused the catalyst to undergo frequent replacement, requiring the Ozone-BAF system to be shut down. It's advised that future projects performed during hot-weather periods be equipped with heaters upstream of the destruct catalyst to drive out excessive moisture. This issue was associated with the pilot-scale equipment and is not typically an issue with full-scale equipment.

Advanced Oxidation

Unlike the other unit processes, UV-AOP was operated in a batch mode only once a week during sampling. The AOP system was operated in batch mode because the process required constant operator attention. Also, instead of renting separate UV-AOP systems for each process train, one UV-AOP system could be used in a batch mode operation. The UV lamps always operated at the same power setting, and the feed flow rate was varied using manual valves to reach the target dose. Based on the feed flow rate, operators used an Excel spreadsheet to calculate the required chemical feed rate; they then manually adjusted the speed on the chemical dosing pump.

The AOP system was manufactured in Switzerland and operated on a 50-Hertz (Hz) power supply, which is different from the 60-Hz supply used in the Unites States. To convert power to the proper setting required for the AOP system, an additional power inverter and transformer were located outdoors adjacent to the AOP system in an enclosed container. While the direct cause of the error is unknown, the AOP system stopped working in August 2017 during the R&D testing at Buckman WRF. An error message was displayed on the power inverter, and operators called upon advice from JEA electricians, the contractor who installed the equipment, the AOP system manufacturer, and the power supply manufacturer (working remotely from Switzerland). Despite best efforts, the AOP system remained inoperable for approximately three weeks until a rental power inverter unit was obtained from a U.S.-based company, shipped to the R&D plant at Buckman WRF, and installed by a certified electrician.

Safety

Safety was the highest priority for the operation of the R&D equipment. Significant onsite hazards included high-strength chemicals, tripping hazards due to the temporary nature of the facility, heat exhaustion, etc. The CDM Smith operators were trained by the chemical supplier to safely store, pump, and transfer chemicals from bulk storage drums to day tanks required by the UF-LPRO-AOP and Ozone-BAF-AOP treatment trains. To ensure safety while handling chemicals, a protocol was created to define the following:

- Personal protective equipment that should be worn with each type of chemical
- Procedures for transferring chemicals
- Procedures for addressing chemical spills
- Procedures for chemical storage

The chemical storage area and path for chemical transfer were arranged to make the transfer of chemicals as convenient and safe for operators as possible. In addition, several ambient ozone analyzers were located inside the equipment buildings to monitor ambient ozone and shut down the ozone unit if levels reached the short-term exposure limit. If an alarm condition occurred, a light beacon would blink outside the building to indicate whether it was safe to enter.

Conclusions and Recommendations

Operational data and water quality monitoring results from this study demonstrate the feasibility of both water purification technologies to produce purified water that meets drinking water quality standards and goals established for the R&D testing, but the UF-LPRO-AOP process exhibited more reliable operation and was less subject to variations in source water quality. Based on this comparison, and along with the life cycle cost estimates provided in the cost evaluation report, CDM Smith recommended the UF-LPRO-AOP system for the demonstration and implementation of JEA's water purification program.

If a utility is considering the development of a potable reuse R&D pilot program, the information presented will provide a better understanding of operator responsibilities, process actions, and lessons learned from the 10-month R&D study in Jacksonville.

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