Advanced Treatment

THE CHALLENGE

The changing landscape of constituents of emerging concern (CECs), pathogens, and disinfection byproducts (DBPs) in drinking water, as well as increasingly restrictive discharge limits for receiving waters and the need to diversify water supplies through reuse, have led to advances in treatment technologies. These approaches expand available water supplies by making less pristine water sources economically feasible to treat and offsetting demand on traditional potable water supplies.

Drinking water plants may employ advanced treatment processes such as carbon adsorption, membrane treatment, ozone, ultraviolet (UV) disinfection, and biofiltration, or a combination of these solutions. Similar advanced treatment strategies at water resource recovery facilities (WRRFs) also remove pathogens, salts, nutrients, organic compounds, and other pollutants—increasingly to produce potable water through indirect or direct potable reuse.

THE RESEARCH

The past several decades have seen increased development and commercialization of advanced treatment strategies and technologies to improve water quality. Since the 1980s, WRF has funded over 250 projects to help utilities understand, implement, and benefit from advanced treatment methods and technologies. WRF has partnered on this work with the U.S. Environmental Protection Agency (EPA), the U.S. Bureau of Reclamation, the California State Water Resources Control Board, Water Research Australia, and others.

Biofiltration

Biofiltration, also known as biological filtration or biologically active filtration (BAF), is the process of allowing microorganisms to colonize water plant filters to remove biodegradable compounds from water. The microbial growth attached to the filter media (biofilm) consumes the organic matter that would otherwise flow through the treatment plant and into the distribution system.

Biofiltration's role has expanded to include the removal of pharmaceuticals and personal care products (PPCPs), DBPs, inorganic compounds, and more. Since many utilities already operate conventional granular media filters, converting them to biological mode can extend the bed life of the filters while meeting water quality objectives, without additional capital investments. Biofiltration's potential savings over costly, energy-intensive, or waste-generating advanced treatment techniques are a significant benefit for utilities.

WRF has supported biofiltration research for over three decades, helping the water community establish baseline knowledge on the design and operation of biofilters (e.g., filter media type, filter backwashing). Furthermore, in 2012, WRF launched a biofiltration research focus area to determine biofiltration's effectiveness at removing contaminants, define benefits and communicate them to key stakeholders, and provide utility guidance on optimizing biofiltration.

Despite this progress, there was not a single point of reference that clearly identified how to design, operate, monitor, and maintain biofilters. Industry experience indicates that most biofilters today are still operated on an incidental basis without a clear strategy for optimizing biological activity or overall biofilter performance. Recognizing these needs, WRF supported *Biofiltration Guidance Manual for Drinking Water Facilities* (4719) to provide the most comprehensive set of practical biofilter design and operational guidance materials currently available to the drinking water industry and to improve the effectiveness and maximize the reliability of biofiltration.

Membrane Treatment

The use of membranes for water treatment has risen significantly in recent decades. Membrane processes include low-pressure membranes, such as microfiltration (MF) and ultrafiltration (UF), and high-pressure membranes, such as nanofiltration (NF) and reverse osmosis (RO). Advances in membrane treatment technology will continue to allow utilities to treat less desirable water supplies.

RO and NF membranes play key roles in desalination, potable reuse, and many challenging industrial purification applications. Several regulations focusing on the control of waterborne diseases impact treatment systems employing RO and/or NF. Removal of waterborne microbes and pathogens is measured by the microbial log removal value (LRV); however, the industry standards underestimate the actual LRV from RO and NF processes. *New Techniques, Tools, and Validation Protocols for Achieving Log Removal Credit Across NF and RO Membranes* (4958) sought to identify direct integrity test methods and perform long-term validation testing to demonstrate *Giardia*, *Cryptosporidium*, and enteric virus LRV credit for high-pressure RO and NF membrane systems.

WRRFs traditionally use activated sludge for treatment, but alternatives like anaerobic dynamic membrane bioreactors (AnDMBR) are being considered to cut costs. AnDMBR employs a biofilm on a coarse support to filter solids from wastewater; however, it faces fouling and methane emission issues. *Next Generation Anaerobic Membrane Bioreactor for Low Temperature Domestic Wastewater Treatment: Pilot* (4876) developed the recirculating AnDMBR (R-AnDMBR), utilizing a high-surface-area filtration structure for biofilm formation and continuous liquid recirculation. Operating at room temperature, R-AnDMBR showed potential for net energy-positive municipal wastewater treatment, especially in warmer climates, with lower maintenance and higher throughput compared to existing membrane bioreactors, and the cost was 38% lower compared to AnMBRs.

Ozone

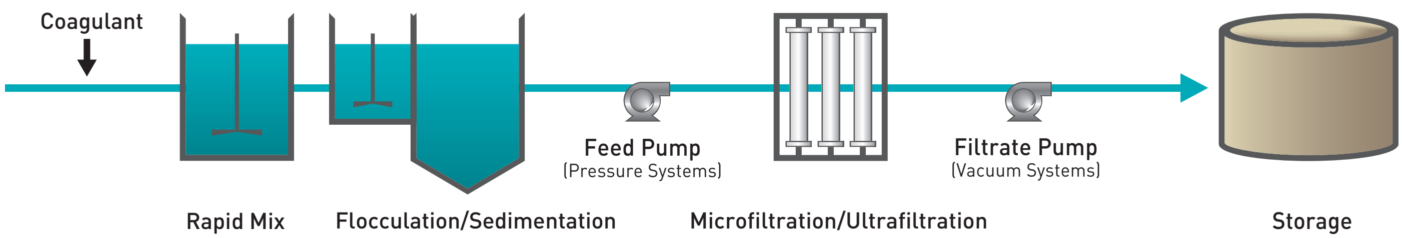
Ozone is a popular choice for meeting disinfection and oxidation needs in drinking water and wastewater treatment. In addition to disinfection, ozone provides other benefits such as oxidation of micropollutants, iron, and manganese; and enhanced coagulation/flocculation efficiency. This often reduces chlorine demand, which subsequently decreases the formation of DBPs.

WRF has funded and published nearly 40 projects on ozone treatment since the early 1990s, with many early projects looking at ozone for drinking water treatment. More recently, projects have focused on ozone dissolution systems, and how ozone treatment can be tailored and optimized for wastewater treatment and potable reuse applications.

In 1991, WRF published *Ozone in Water Treatment: Application and Engineering* (421), which includes information on the design, operation, and control of the ozone process within drinking water plants. The report applies almost 100 years of European ozone design and operations experience to the North American regulatory and utility environment. The report is essential to all water utilities, design engineers, regulators, and plant managers and supervisors interested in effectively implementing ozone.

While conventional ozone application has proven effective, it can lead to rapid bubble departure from the solution due to high buoyancy, resulting in a short contact time for ozone dissolution in water. In recent years, there has

TYPICAL MICROFILTRATION/ULTRAFILTRATION WATER TREATMENT PROCESS



been growing interest in using nanobubble (NB) technology during ozonation, as NBs exhibit extended solubility in water, thereby significantly enhancing ozone's disinfection capacity and residual activity. *Investigation of Nanobubble Technology for the Removal of MIB and Geosmin from Drinking Water* (5070) examined and evaluated NB technologies for the removal of 2-methylisoborneal (MIB) and geosmin from water.

Results from Use of *Ozone in Water Reclamation for Contaminant Oxidation* (Reuse 08-05/1645), released in 2014, characterized the use of ozone in wastewater treatment applications with respect to bulk organic matter transformation, contaminant oxidation, microbial inactivation, and the formation of DBPs and other transformation products. This study demonstrates ozone's ability to reduce estrogenicity of secondary effluent, which has direct implications for discharge to environmentally sensitive surface waters. Ozone is also an effective disinfectant, which translates to public health benefits in recycled water applications where direct contact is possible. Ozone can be used simply to oxidize a wide range of compounds, microbes, and bulk organic matter to increase the chemical, microbiological, and aesthetic quality of the effluent in a conventional water resource recovery facility. This research also features cost estimates for the use of ozone in advanced treatment processes and hypothetical treatment trains.

Ozone is sometimes paired with other unit processes for enhanced treatment outcomes. For example, hydrogen peroxide addition accelerates ozone decomposition into hydroxyl radicals for contaminant oxidation. In another common treatment pairing, the synergy between ozone and biofiltration creates an effective multi-barrier approach. WRF recently published *Optimization of Ozone-BAC Treatment Processes for Potable Reuse Applications* (4776), which addresses the design and considerations of ozone/biofiltration for potable reuse projects.

UV Disinfection

UV disinfection is an effective component of the multi-barrier approach to controlling pathogens in drinking water. WRF has funded more than 50 UV projects over the past several decades. Published in 2019, *Design and Validation Protocols for UV Disinfection Systems* (4791) developed and applied stochastic approaches for analysis of process performance in UV disinfection systems. The stochastic methods used in this research allow users to accurately predict process performance in UV disinfection systems, including inherent variability. By applying this method, UV disinfection system designs can be improved to address this variability directly, rather than relying on safety factors (i.e., over-design) as a means of ensuring process reliability. As such, the application of these methods has the potential to reduce capital and operating costs of UV disinfection systems.

SOLUTIONS IN THE FIELD: Trinity River Authority – Biofiltration

The Trinity River Authority (TRA) of Texas provides water and wastewater treatment, reservoir services, as well as recreational amenities, within the nearly 18,000-square-mile Trinity River basin. TRA owns and operates the Tarrant County Water Supply Project (TCWSP), which supplies drinking water to five customer cities.

At TCWSP, chlorine and chloramines were historically used as the primary disinfectant, with ozone used for taste and odor control; however, TRA wanted to replace chlorine and chloramines with ozone for primary disinfection. As part of this switch, they needed to implement biological filtration to control organics and manganese in the water supply.

In partnership with Carollo Engineers, TRA developed a WRF Tailored Collaboration project, *Optimizing Filter Conditions for Improved Manganese Control During Conversion to Biofiltration* (4448), to test ways to stabilize the manganese that existed on their current filter media and accelerate the biological growth. Through a pilot study, TRA experimented with different ways to optimize performance on the filter media by adding nutrients in the form of carbon and phosphorus and adjusting oxidation-reduction potential and pH.

The research proved successful—TRA completed its full-scale testing in 2016 and was able to proceed to full implementation of biofiltration at TCWSP.

Potable Reuse
More and more utilities are exploring direct potable reuse (DPR), where purified wastewater is introduced into a drinking water treatment facility or directly into the water distribution system. Implementing DPR and eliminating the environmental buffer offer potential operational advantages as well as benefits to a utility's bottom line, but many utilities needed to learn more.

To provide solutions, WRF launched a multiphase research project to explore the benefits and tradeoffs of various treatment process trains. The resulting report, *Examining the Criteria for Direct Potable Reuse* (Reuse-11-02/1689), contains criteria for assessing the effectiveness of different advanced treatment trains, taking some of the top microbial and chemical concerns into consideration. The research includes the first U.S.-based pilot of an advanced treatment train for DPR under realistic operating conditions. The water quality criteria developed in this project have been used by several states, including California, that are developing water quality criteria for potable reuse.

Although many treatment strategies for potable reuse rely on RO, alternatives to RO can also achieve potable water quality in potable reuse scenarios. One option, combining ozone with BAF, can yield a viable water supply, is sustainable, and can be used to remove pathogens and a variety of organic compounds. In 2018, WRF released findings from a study that looked at the feasibility of DPR using ozone-BAF treatment without RO to achieve potable quality water. The study, *Ozone Biofiltration Direct Potable Reuse Testing at Gwinnett County* (Reuse-15-11/4777), not only showed that ozone-BAF could provide high-quality water, but it could do it at less than half the cost of RO-based treatment. By comparing IPR to DPR in Gwinnett County, several potential operational benefits were identified for DPR including reduced ozone demand, lower filter headloss accumulation rates, and mitigation of source water quality excursions. In 2018, the project won a Transformational Innovation Award at the 33rd Annual WateReuse Symposium and Excellence in Environmental Engineering and Science Grand Prize for Research from the American Academy of Environmental Engineers and Scientists.

As mentioned above, WRF research has demonstrated the ability of membrane bioreactor (MBR) systems to provide virus, protozoa, and bacteria removal. Similar to RO and NF processes, however, a gap exists in the regulatory application of pathogen log removal value (LRV) credits for MBR systems within potable reuse systems. To explore solutions, WRF investigated the Australian WaterVal program, which describes three tiers of validation to obtain LRV credits for viruses and pathogens. *Evaluation of Tier 3 Validation Protocol for Membrane Bioreactors to Achieve Higher Pathogen Credit for Potable Reuse* (4959) identified modifications needed to adapt the Tier 3 protocol for the United States and developed implementation recommendations for a Tier 3-style regulatory approach for increased operational flexibility in reuse facilities.

WHAT'S NEXT?

Conventional UV disinfection relies on mercury vapor lamps that emit radiation at 254 nm. UV disinfection is highly effective in pathogen control, however environmental, economic, and applicability issues should be considered when using conventional UV and full-scale ultraviolet light emitting diode (LED UV) technologies. *Feasibility of Full-Scale Implementation of LED UV Disinfection* (5173) will perform a quantitative assessment of the feasibility of LED UV water disinfection reactors for drinking water and wastewater treatment applications. The analysis will consider disinfection performance, technological, economic, and environmental feasibility against both new and Hg-replacement installation scenarios. In addition to this, two new WRF projects (5213 and 5218) will analyze the effectiveness of LED UV irradiation in mitigating *Legionella*, reducing biofilm formation, and enhancing water quality.

Conventional ozone application using macro bubbles can lead to rapid bubble departure from the solution due to high buoyancy, resulting in a short contact time for ozone dissolution in water. In recent years, there has been growing interest in using NBs technology during ozonation, as NBs exhibit extended solubility in water, thereby significantly enhancing ozone's disinfection capacity and residual activity. The stability and reactivity of NBs depend on factors such as bubble size, zeta potential, and interfacial characteristics. Solution properties, including temperature, pressure, ion concentration, pH, presence of organic matter or impurities, and surfactants, as well as saturated gas concentration, also influence the behavior of NBs. A new project, *Ozone Nanobubbles Technologies for Water Treatment* (5237), is underway to provide further knowledge in this area.

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