Moving from Non-Potable to Potable Reuse: What Do We Do with UV?

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Abstract

When employed as part of the treatment processes for water recycling, UV technology has different treatment targets and objectives in potable reuse applications from what is expected in non-potable reuse applications. The typical disinfection UV-dose requirements for non-potable reuse are far less than what are required in a UV-AOP process. This poses significant challenges to the conversion of a UV facility from UV-disinfection for non-potable reuse to UV-AOP for potable reuse. To address these challenges, a study was performed to identify key issues, such as regulatory compliance and technology applicability. The study also provides a potential implementation approach, including facility needs, costs and a sensitivity analysis. Results have shown that the conversion from UV-disinfection to UV-AOP is sometimes practically feasible and makes economic sense for treatment plants that own existing UV systems. Closed-vessel UV equipment is more suitable for disinfection applications than open channel systems if converting to UV-AOP for potable reuse is anticipated. The general increase in UVT from extensive treatment in potable reuse applications upstream of UV equipment could significantly mitigate the increase in UV dose requirements for downstream UV-AOP, thereby reducing the amount of incremental equipment for conversion. The sensitivity analysis also shows there is a significant increase of annual O&M cost arising from the use of chemicals in the UV-AOP process.

Introduction

To address increasing water shortages in California and a few other southern states in the United States, the current trend in water reuse is moving from non-potable reuse towards direct or indirect potable reuse to maximize the potential of all available water resources. Significant efforts have been made among water agencies and the water industry to define the guidelines and criteria needed for potable reuse to address advanced treatment of both microbiological and chemical contaminants. Reduction of chemical contaminants of concern, such as N-nitrosodimethylamine (NDMA) and 1,4-dioxane, often requires the treatment train to include an advanced oxidation process (AOP) step. One of the AOP technologies has demonstrated its effectiveness involving UV in combination with addition of hydrogen peroxide, ozone or more recently proposed hypochlorite, to destroy persistent chemical contaminants. A number of UV-AOP processes are in operation in Southern California for NDMA or 1,4-dioxane reduction.

UV technologies have been widely applied in disinfection in compliance with non-potable reuse criteria established by water authorities, for example, the California Water Recycling Criteria (California Code of Regulations, Title 22). With the increasing interest in potable reuse, it is a natural reaction for most water recycling plants using UV systems to explore the option to implement UV-AOP as part of their advanced treatment process for potable reuse. However, the typical UV dose requirements for non-potable reuse disinfections are far less than what are required in a UV-AOP process, that is, less than 100 mJ/cm^2 vs. hundreds or often over 1,000 mJ/cm^2 for UV-AOP. This poses significant challenges to the conversion of a UV facility from UV-disinfection to UV-AOP. To address these challenges, a study was performed to identify issues, such as regulatory compliance and technology applicability. The study also provides a potential implementation approach including facility needs, costs and a sensitivity analysis.

Objectives and approach

The purpose of the study is to provide current and future UV owners a potential pathway of UV implementation for potable reuse. The study focuses on upgrades or expansions from existing UV systems originally designed for UV-disinfection for non-potable reuse to achieve the treatment goal for UV-AOP for potable reuse with robustness, reliability and operational flexibility.

The objectives of the study are threefold: (1) Identify the current regulatory requirements of non-potable reuse vs. potable reuse and define the potential impact on UV system conversion; 2) Identify UV technologies for implementation and future conversion which are applicable, cost effective and sustainable; and 3) Present estimated costs in a range of UV system capacities comparing UV-disinfection for non-potable reuse and UV-AOP for potable reuse and provide implementation costs (per unit flow rate, million gallons per day, MGD) for UV disinfection system in four selected capacities that are typical reuse flow projections.

The initial step of the study was to collect and summarize the available and anticipated treatment requirements for UV in non-potable and potable reuse, including indirect and direct potable reuse. In addition, a UV technology that is commonly applicable for UV-disinfection to UV-AOP conversion was selected for sensitivity analysis. Findings from the initial steps of the study are described in the following sections.

Non-potable reuse vs. potable reuse

UV technology, when employed as part of the treatment processes for water recycling, has different treatment objectives or treatment targets in non-potable reuse and potable reuse applications.

In non-potable reuse applications, UV is the disinfection process for reduction of microbial containments, or pathogen inactivation and typically follows tertiary filtration or membrane processes. Delineated in California Title 22 non-restricted reuse criteria, the water reuse requirements pertaining to the disinfection process include bacteria and virus count limitations: "Disinfected by a disinfection process that has been demonstrated to inactivate and/or remove 99.999 percent of the plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater." Disinfection must meet the following criteria: "the median concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed." Design UV doses are well defined for achieving the regulatory requirements for non-potable reuse. The UV design guidelines set forth by National Water Research Institute (NWRI) are widely adopted for UV disinfection system design for non-potable reuse applications. Pilot demonstration usually is not required. The NWRI Guideline also provides testing protocol for performance verification of commissioned UV systems.

In potable reuse applications, UV often is employed as an advanced oxidation process (AOP) for reduction of trace chemical containments, or micro-pollutants. The UV-AOP mechanisms are photolysis and hydroxyl radical generation, which involve chemicals as the source of hydroxyl radicals in addition to high energy input. UV-AOP is one of the three typical treatment technologies of Full Advanced Treatment (FAT) following microfiltration and reverse osmosis (RO). In addition to microbial contaminant criteria, California Title 22 indirect potable reuse criteria include specific requirements for the oxidation process in FAT. An oxidation process, such as UV-AOP, has to demonstrate consistent destruction of a bundle of selected indicator chemicals or "provide no less than 0.5-log reduction of 1,4-dioxane." Site-specific bench or pilot studies are required to determine UV doses to achieve the 0.5-log 1,4-dioxane reduction. UV doses of UV-AOP to achieve the required 1,4-dioxane log reduction have been shown in the realm of UV photolysis, which is approximately an order of magnitude higher than what is required for UV-disinfection in non-potable reuse. Under UV photolysis, pathogen reduction becomes a side benefit. California Title 22 limits the pathogen reduction benefit from UV-AOP. For each regulated pathogen (enteric virus, *Giardia cyst* or *Cryptosporidium oocyst*), FAT is credited for maximum 6-log reduction credit.

Comparison between UV-disinfection for non-potable reuse and UV-AOP for potable reuse in terms of treatment objectives, testing requirements and energy requirements is summarized in Table 1.

Table 1. UV-disinfection vs. UV-AOP: treatment objectives, energy and testing requirements

	UV disinfection	UV-AOP
Treatment target	Pathogens	Trace contaminants
UV dose	Usually defined for log-reduction credits or numeric target	No set dose target, but rely on reaction kinetics. Site-specific bench or pilot studies to determine
Off-site testing	Third-party evaluation	Not required and not a common practice
On-site testing	Spot-check bioassay if NPR (only in California)	Pilot demonstration and full-scale performance usually required
Energy requirements	Relatively less ambiguous due to defined target UV dose	Variable due to target contaminant, oxidant concentration, UV lamps (LP or MP) and water quality (competitor scavengers, e.g., nitrate)

UV technology applicability

Current UV installations for non-potable reuse applications are based mainly on two major UV configurations: an open-channel UV system and a closed-vessel UV system. Open channel UV systems are common in non-potable reuse applications, particularly with upstream tertiary treatment processes using media filtration. Closed-vessel UV systems

page 6 ▶

◀ *page 5*

are commonly installed downstream of membrane filtration, such as a membrane bioreactor in non-potable reuse applications. Both systems can achieve the disinfection goal for the current design, as well as have the potential to be expanded to provide the higher UV doses needed for UV-AOP. However, membrane technologies that have been employed in indirect or direct potable reuse treatment trains, such as microfiltration and reverse osmosis, typically produce pressurized effluent. As such, using closed-vessel UV systems in the UV-AOP process downstream is more appropriate to handle the pressurized effluent.

A closed-vessel UV system can be equipped with either low-pressure high-output (LPHO) or medium-pressure (MP) lamps. A closed-vessel UV system also may have the capability of being upgraded and expanded from regular disinfection to a UV-AOP reactor. Some UV manufacturers offer closed-vessel UV systems for both disinfection and UV-AOP applications. Though modifications may be needed, the UV systems to be installed in the current non-potable reuse design can be employed within its lifetime in the UV-AOP treatment process for future potable reuse treatment applications.

Table 2 summarizes the comparison of UV technology application in UV-disinfection and UV-AOP in terms of its status of application in water recycling, lamp technologies and reactor configurations.

Table 2. UV-disinfection vs. UV-AOP: Technology applicability

	UV disinfection	UV-AOP
Low-pressure high-output lamps	Common	Common
Medium-pressure lamps	Common, smaller footprint but relatively higher energy demand	Common, smaller footprint and used for seasonal contaminant treatment
Open-channel	Common, but mostly for non-potable reuse or secondary effluent	Less common to accommodate pressurized upstream flow
Closed-vessel	Common for DW and non-potable reuse	Dominating

For this study, a closed-vessel UV system equipped with LPHO UV lamps is used in the subsequent sensitivity analysis.

Sensitivity analysis

As a part of this study, a sensitivity analysis was performed to evaluate the impact of the UV-disinfection to UV-AOP conversion in terms of facility requirements and costs. The sensitivity analysis included four selected capacities or flow scenarios that are in the capacity range of typical water recycling facilities.

UV systems with various flow capacities in the evaluation are developed based on the treatment target and design criteria. For UV-disinfection, the UV system receives membrane filtration effluent and provides disinfection prior to the designated non-potable uses. For UV-AOP, the UV system receives RO permeate and provides oxidation of chemical contaminants prior to the designated indirect or direct potable uses.

In both non-potable and potable reuse applications, major components of the UV system include lamps and reactors. All UV facilities in the evaluation are sized based on a closed-vessel UV system equipped with LPHO UV lamps.

Besides flow rate, disinfection with UV is achieved and controlled with two functional parameters: UV dose and UVT, which represents recycling water quality. The required dose value for non-potable reuse applications is well defined via bioassay testing. In this evaluation, a UV dose of 80 mJ/cm^2 and a minimum UVT of 65% are designated for membrane filtration effluent based on NWRI UV Disinfection Guidelines for Water Reuse (2012).

The figure-of-merit Electrical Energy per Order of contaminant removed (EEO) is used in the sizing and control of UV-AOP systems (Bolton et al. 2001). EEO is an empirical function representing various design conditions that potentially impact the oxidation process, such as lamp output, flow rate, and contaminant log reduction kinetics. In this evaluation, an EEO of 0.3 kWh/1,000 gal/order is used for UV system sizing. This EEO number is within the range that have been proven effective and reliable for 0.5-log 1,4-dioxane reduction in a number of pilot and full-scale operations. In addition, minimum UVT of 95%, which is typical for microfiltration and RO permeate, is used for UV system sizing.

Evaluation criteria used as the basis for UV facility sizing and cost estimates are summarized in Table 3. These design criteria served as the basis for UV equipment sizing, facility layouts and O&M cost estimates.

The UV-AOP process requires a combination of UV with chemical oxidants, such as hydrogen peroxide, ozone, or more recently proposed hypochlorite, to enhance the generation of hydroxyl radicals to more effectively destroy the persistent chemical contaminants. Therefore, to implement the UV-AOP process, a chemical injection and storage or ozone generation system may need to be added. In the sensitivity analysis, hydrogen peroxide is used as the oxidant for hydroxyl radical generation, and sodium hypochlorite is used as quenching chemical for residual hydrogen peroxide.

Table 3. UV-disinfection vs. UV-AOP: Evaluation criteria for sensitivity analysis

	UV disinfection	UV-AOP
UV system capacity	Assumed for the purpose of this sensitivity analysis: 2 MGD, 4 MGD, 8 MGD, 10 MGD	
Treatment target	For non-potable reuse: total coliform 2.2 MPN/100mL; 5-Log polio virus reduction	For potable reuse: 1,4-dioxane 0.5-Log reduction
System components	Closed-vessel UV system with LPHO lamps	Closed-vessel UV system with LPHO UV lamps; H_2O_2 as oxidant or source of hydroxyl radical; sodium hypochlorite for hydrogen peroxide residual quenching
Design UV transmittance (UVT)	Membrane permeate 65%	Microfiltration and RO permeate 95%
Design dose	NWRI guideline dose criteria: 80 mJ/cm^2	E_{EO} (electrical energy per order of contaminant removed) based dose criteria: 0.3 kWh/1,000gal/order; 5 mg/L H_2O_2

UV facilities are sized based on the criteria listed in Table 3. The UV equipment used for sensitivity analysis is selected from the UV technologies that have been through the validation process with a sizing algorithm established

page 8 ▶

◀ *page 7*

and approved for use in water recycling applications. The UV system selected for evaluation is a closed-vessel system equipped with 250-watt UV lamps. Redundancy is typically required for reuse facilities. In closed-vessel UV system, redundancy is provided by means of an extra parallel train. UV-disinfection and UV-AOP system components and their sizing are summarized in Table 4.

Table 4. UV-disinfection vs. UV-AOP: system sizing under selected treatment capacities

Flow rate	2 MGD	4 MGD	8 MGD	10 MGD
UV-disinfection				
Number of reactor chains	3	4	6	8
Number of duty reactors	2	3	5	7
Number of duty lamps	144	216	360	504
Maximum power draw (kW)	36	54	90	126
UV-AOP				
Number of reactor chains	3	5	8	10
Number of duty reactors	2	4	7	9
Number of duty lamps	144	288	504	648
Maximum power draw (kW)	36	72	126	162

The monetary analysis of the UV systems was performed for the equipment cost and O&M cost of each UV system.

The equipment cost of the closed vessel UV system selected for this analysis was obtained from an equipment manufacturer that provides the UV equipment that meets all the evaluation criteria in Table 3.

The annual O&M costs of a UV system mainly consist of power cost, lamp and ballast, and other consumable parts replacement cost. O&M cost of UV-AOP systems also includes the cost of chemicals that are used as oxidants or a source of hydroxyl radicals. For the annual O&M cost estimate, assumptions were made for the unit cost of power and chemicals purchased. Major replacement costs for UV system were obtained from the UV equipment manufacturer. The annual replacement cost of each major part is prorated based on its warranted lifetime. The O&M cost in this evaluation only includes major items that would differentiate the UV systems in the evaluation, such as power, chemicals cost and consumables replacement. Common O&M costs, such as labor and compliance testing costs, are not included.

Unit flow costs, or $/MGD, were obtained by normalizing the equipment cost, power cost and annual O&M cost with the system treatment capacity. Normalized cost curves are developed with $/MGD over the range of evaluated system capacity scenarios and presented in Figures 1 through 3.

- Figure 1: UV equipment cost per MGD system capacity
- Figure 2: Annual power consumption per MGD system capacity
- Figure 3: Annual O&M cost per MGD system capacity

Figures 1 through 3 show the cost impact of expansion from UV-disinfection to UV-AOP in terms of energy cost and annual O&M cost, as well as additional UV equipment investment. These figures can be used when estimating conversion installation cost, O&M cost and power consumption of a UV system with UV system treatment capacity close to the treatment capacity in the evaluation (i.e., 2 to 10 MGD).

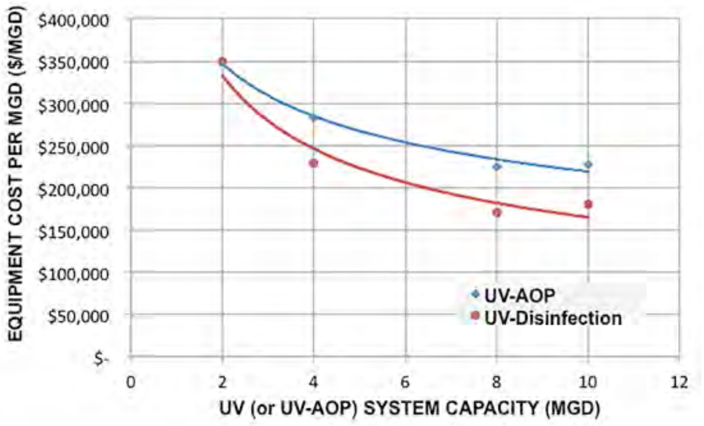

Figure 1. UV equipment cost per MGD system capacity

page 10 ▶


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◀ *page 8*

As shown in Figure 1, the unit equipment cost curve demonstrates a common Economy of Scale in which the UV equipment cost per MGD decreases with increasing system capacities. The blue line is always above the red line showing that, in general, additional UV equipment is required when converting UV-disinfection to UV-AOP.

However, the cost increase is not quite in proportion to the required dose increase. As discussed previously, the typical UV dose requirements for non-potable reuse disinfection are far less than what are required in a UV-AOP process. The dose for UV-AOP is typically 10 times of the dose for UV-disinfection. The small increment equipment cost also is shown in Table 4, where one or two extra reactors are required for conversion in the capacity range of the evaluation.

The other system design parameter, UVT, plays an important role in equipment expansion for conversion from UV-disinfection to UV-AOP. From non-potable reuse to potable reuse, more advanced or rigorous treatment, such as FAT including ultrafiltration and RO, is employed upstream of UV-AOP in order to meet stringent water quality criteria for potable reuse. Application of FAT significantly improves the effluent UVT, from 65% to greater than 90%. The huge increase in the UVT could significantly compensate the increase in UV dose requirement and therefore reduce the amount of additional equipment.

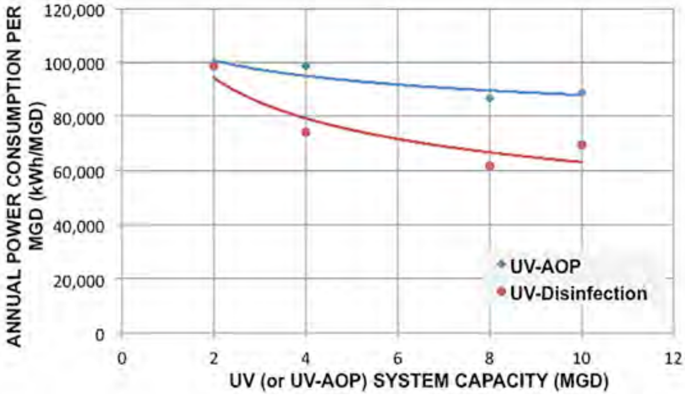


Figure 2. Annual power consumption per MGD system capacity

Referring to Figure 2, the power consumption increases with increasing amount of duty equipment, and the increase of power consumption for conversion follows similar trend of equipment cost increase (Figure 1). The power consumption for a UV-disinfection system is in a range of 60,000 to 90,000 kWh per year per MGD treatment capacity of the system. The power consumption for a UV-AOP system is in a range of 90,000 to 100,000 kWh per year per MGD treatment capacity of the system. The power consumption increases 20% to 30% per MGD treatment capacity for conversion. The smaller the system, the higher the unit power consumption is due to the fact that UV system is modulating by design. Smaller systems typically consist of limited number of reactors, which results in less flexibility in operation for power saving.

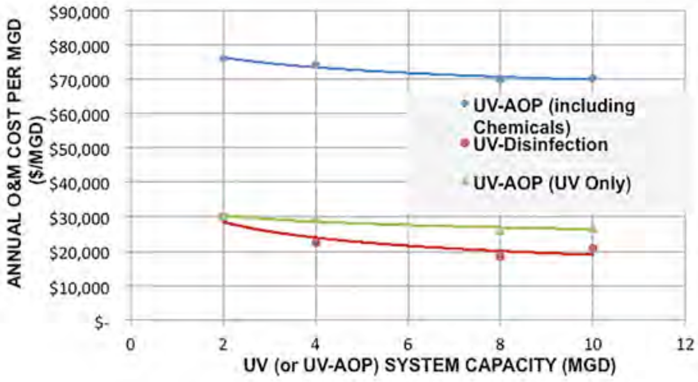


Figure 3. Annual O&M cost per MGD system capacity

Figure 3 shows two major O&M cost items for a UV system: power consumption and annual equipment consumable parts replacement. These two major cost items share almost half of the total annual O&M cost of the UV systems in the sensitivity analysis. Both increase with increasing amount of duty equipment for the conversion from UV-disinfection to UV-AOP. The annual O&M cost increase for the UV system only shows up to 30% to 40% for the scale of treatment capacities in the evaluation.

The significant increase of annual O&M cost arises from the use of chemicals in the UV-AOP process. Figure 3 shows, when cost of chemicals is included, the annual O&M cost per MGD treatment capacity of a UV-AOP system is approximately 3 to 4 times higher than that of a UV-disinfection system typically with no chemicals involved in operation. Chemicals are not only needed as the oxidant or source of hydroxyl radicals in the AOP process, but are also demanded to quench the residual oxidant post the AOP process. A typical UV-H_2O_2 AOP process would require a hydrogen peroxide concentration from 2 mg/L up to greater than 10 mg/L depending on the water quality and the level of treatment is needed. In this sensitivity analysis, hydrogen peroxide is used as oxidant and sodium hypochlorite is used as the residual hydrogen peroxide quenching agent. A hydrogen peroxide dose of 5 mg/L was used in the AOP calculation. A 10% hydrogen peroxide reduction across the UV reactor was assumed, with 90% left for residual quenching by chlorine. Quenching chlorine is provided with a 12.5% sodium hypochlorite solution.

Converting UV-disinfection to UV-AOP

The analysis summarized above confirms that converting a UV facility from UV-disinfection to UV-AOP is technically and practically feasible. System conversion or facility planning needs to consider the significant difference of UV implementation in terms of the treatment target and design criteria for non-potable vs. potable reuse. The sensitivity analysis applied in this study has shown, for any existing UV facilities, upgrading from UV-disinfection to a UV-AOP is a viable and cost-effective approach to keep the facility in compliance with the stringent water quality criteria for reuse applications. For treatment facilities that are implementing a non-potable reuse UV-disinfection today, while bearing the potential capability of future upgrade for potable reuse using UV-AOP, the sensitivity analysis herein provides key considerations for facility planning and a glimpse of cost impact.

UV technology selection

One key consideration is technology applicability. With treatment requirements for both non-potable reuse UV-disinfection and potable reuse UV-AOP, there are a limited number of UV technologies that possess the effectiveness and capability for both. Using closed-vessel UV systems in the UV-AOP process downstream might be more appropriate; the selected UV system may need to have the capability of being upgraded and expanded from UV-disinfection to a UV-AOP reactor.

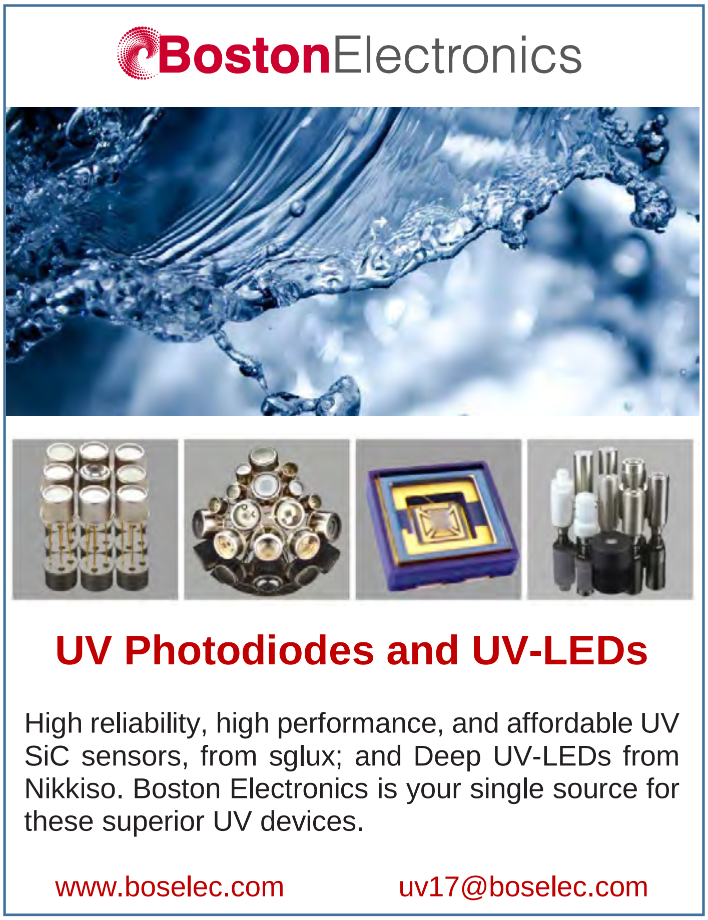
Additional capital investment

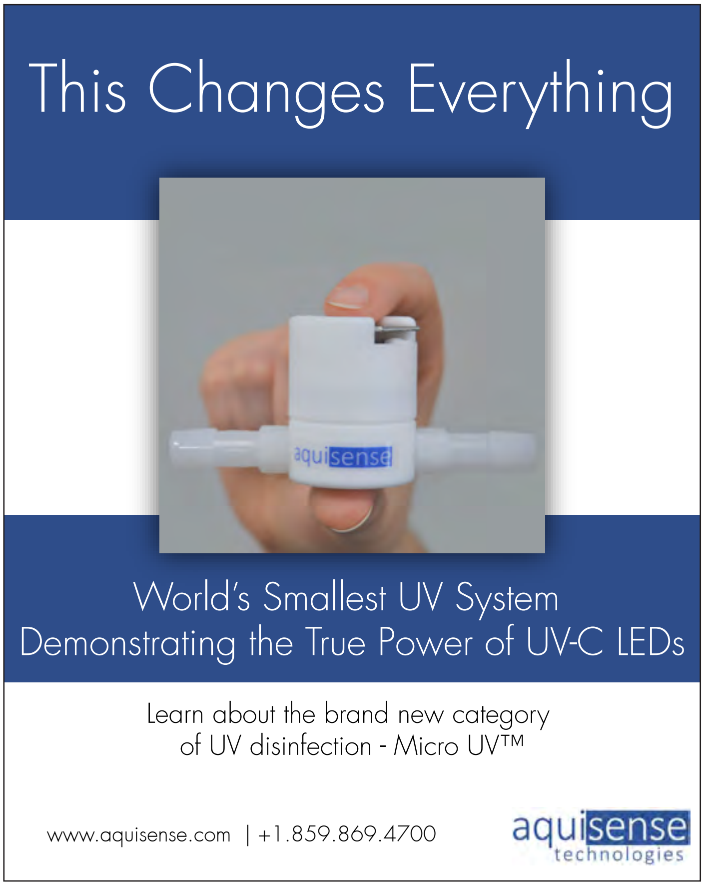
Additional capital investment is expected for this type of conversions. The higher level of UV doses can be achieved by either adding more UV equipment, or by lowering the treated flow rate significantly as well as taking advantage of the better water quality from advanced treatment processes upstream of the UV systems. Higher UVT could help increase the delivered dose for UV-AOP application. However, if the current flow capacity is desired to be maintained the same for the potable reuse applications, it is necessary to consider a capacity expansion to accommodate the UV-AOP dose requirements.

Facility requirements

From the sensitivity analysis presented herein, the equipment expansion is expected to be 20 to 30 percent. The capital cost of the expansion is site specific, and is not only from the equipment addition but also the expansion and upgrade of facilities that are associated with the UV system operation.

page 12 ▶





◀ page 11

The UV facility conversion could include, but not limited to, the following:

- More UV equipment: UV system expansion can be achieved by addition of parallel trains or addition of reactors in series, or swap lamps with higher wattage lamps, etc.;
- Additional chemical storage and feed facilities;
- Additional process monitoring and control equipment;
- Update programming to accommodate the higher UV dose needs;
- Integrate UV systems with oxidant dosing equipment;
- Shelter or enclosure for UV equipment, power panel, as well as control equipment.

Additional O&M cost

Additional O&M cost is expected for conversion. Conversion from UV-disinfection to UV-AOP requires higher UV doses therefore additional UV equipment. Annual O&M cost is expected to increase with increasing energy consumption and cost for parts replacement from the additional UV equipment. The sensitivity analysis has shown that the significant O&M increase is due to the addition of chemicals in UV-AOP. UV photolysis alone can destruct some chemical contaminants (e.g., NDMA), but mostly the UV-AOP process requires a combination of UV with oxidants such as hydrogen peroxide, ozone or, more recently proposed, hypochlorite to enhance the generation of hydroxyl radicals to more effectively destruct the persistent chemical contaminants. It is common that multiple chemicals are used in UV-AOP operation, as oxidant for hydroxyl radicals, residual oxidant quenching, and in some cases required as residual for post-AOP disinfection. O&M cost for chemical use is mainly from annual chemical purchases.

AOP validation and demonstration

The UV-disinfection system for non-potable reuse is typically selected and designed with UV technology that would be validated by independent third-party entities following strict validation protocols. The design conditions for UV-disinfection systems are typically well defined and verified with many full-scale installations currently in operation. However, the UV systems used in AOP processes are usually not validated due to the lack of appropriate testing surrogates at the UV dose levels required in AOP processes.

Because of the above points, pre-installation bench scale testing and piloting are necessary to establish robust design criteria. A bench-scale treatability study is typically conducted to confirm effectiveness and efficiency of UV-AOP for designated treatment target, such as 0.5-log reduction of 1,4-dioxane, or 1.2-log reduction of NDMA, etc. After a bench-scale treatability study, an onsite pilot study with site-specific water and quality is recommended. The major elements and key considerations for onsite pilot study include:

> When employed as part of the treatment processes for water recycling, UV technology has different treatment targets and objectives in potable reuse applications from what is expected in non-potable reuse applications.

- Seasonal variation in water quality to be accounted for if applicable;
- Optimize UV energy requirement and chemical dosage;
- Design engineer or independent third party to be involved along with technology vendor;
- Regulators onboard to facilitate the approval process.

Post-installation field validation or demonstration is required for UV-AOP to confirm the effectiveness and efficiency on the treatment performance.

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References

Bolton, J.R.; Bircher, K.G.; Tumas, W; Tolman, C.A. 2001, Figures-of-Merit for the technical development and application of Advanced Oxidation Technologies for both electric- and solar-driven systems, Pure Appl. Chem., (73)4_: 627–637

Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse, August 2016, prepared for California State Water Resources Control Board

Title 22 Code of Regulations, Regulations Related to Recycled Water, June 18, 2014 (Revisions effective on 6/18/14) by California Department of Public Health

Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (2012) 3rd Edition, Published by National Water Research Institute in collaboration with Water Research Foundation