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Determination Method for UV Output Power of Low-Pressure Lamps
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from the IUVA President

After a successful World Congress held in Croatia in September that hosted attendees from 24 countries, I am honored to hand over the presidency of the IUVA to Mr. Oliver Lawal. Thank you to Dr. Regina Sommer and all of the other program committee members for leading this effort. Also, the event would not have been possible without our support team: Gary Cohen, James Kerich and Mickey Fortune.

While many of you know Oliver, a few may not. Oliver is the chief executive officer and president at AquiSense Technologies LLC, and as the founder of the organization, he is able to execute his passion for chemical-free water treatment using UV-C LEDs. He previously served as president of Aquionics Inc., and he held a number of executive engineering and research positions at Wedeco in England, France, New Zealand and Germany. Oliver holds two engineering degrees from Manchester University in the United Kingdom, has been widely published on UV topics, named in various global patents and is considered one of the thought leaders in the practical application of UV-LED’s for water treatment. In addition to his long career in UV, he is an avid motorcyclist and collector of motorcycles, as well as a dedicated husband and father. With Oliver’s forward-looking vision, I am excited to continue working with all of our members to serve the IUVA. Please congratulate Oliver, and also welcome our new board members, Roberta Hofman-Caris, Richard Joshi, Paul Ropic and Dr. Eva Nieminski.

We also have new chairmanship of the technical committee, Dr. Shen Chengyue, who will lead the committee to continue its excellent work. I would like to recognize co-chairs Dr. Linda Gowman and Bryan Townsend, who have taken on a number of challenging issues during their term. Some of these have included the review and comment on the Ten States Standards, which provides guidance to many states for implementing UV for wastewater disinfection, comments on the NWRI 2012 Guidelines and comments on the requirements for Ballast Water Treatment as regulated by the US Coast Guard. The committee initiated efforts on its highest, ongoing priority to address the issues in the draft EPA document, “Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems,” before its release.

While we have a change in organizational leadership, it is important to recognize there are many members that have been active in helping the IUVA meet its mission to advance the science of UV. It is the membership that allows the IUVA to advance important issues in our field. With that in mind, I look forward to seeing you all participate at our next upcoming events. Looking ahead, IUVA is planning for a workshop in Singapore on Nov. 6, 2017, and the America’s Conference will be held in Redondo Beach, California, in February 2018. A UV LED conference will take place in Berlin, Germany, in May 2018. These and other IUVA events continue to be opportunities for technical exchange, education and networking. There are always scientific issues and regulatory challenges, and our organization is critically important for providing an opportunity to address issues that potentially will have significant impact on the application of UV.

Thank you for the opportunity to serve the IUVA, and I’ll look forward to seeing everyone in California in February, where we look forward to a strong technical program at yet another beautiful location!

Kati Bell, IUVA president
Water Reuse Practice Leader at MWH Global

A Message
from the Editor-In-Chief

This IUVA News issue features two articles, a new method for the determination of the total UV output of a UV lamp embedded in a UV reactor and a discussion of issues regarding the use of UV for potable and non-potable water reuse.

Starting with the Winter 2017 issue, IUVA News will aim to have a theme for each issue. The planned themes for the Winter 2017 and Spring 2018 issues are advanced oxidation and UV LEDs. If you would like to submit a paper for one of these themed issues, please send it to me at editorinchief@iuva.org. The deadlines are Nov. 15, 2017, for the Winter 2017 issue (advanced oxidation) and Feb. 15, 2018, for the Spring 2018 issue (UV LEDs).

IUVA News is your quarterly ultraviolet magazine, so please take some time to read it through, and don’t forget the ads. The ads make it possible to publish IUVA News, so please support our advertisers by visiting their websites or contacting them for further information. If you are a marketing manager in a UV company, I encourage you to advertise. You not only will attract direct sales but also enhance your image in the UV community. Email me, and I’ll send you the IUVA News Media Kit. Note that IUVA News publishes short Application Notes highlighting novel and ground-breaking applications of a UV company’s technology. Also, IUVA corporate members are welcome to contribute short announcements to the UV Industry News column.

Jim Bolton, IUVA News editor-in-chief
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- Low Pressure UVC
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- UVB Lamps 295 nm, 310 nm, 320 nm
- UVA Lamps 350 nm, 369 nm
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Moving from Non-Potable to Potable Reuse: What Do We Do with UV?

June Leng¹ and Chengyue Shen²
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2. HDR, Mahwah, NJ; email: chengyue.shen@hdrinc.com

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/cm² vs. hundreds or often over 1,000 mJ/cm² 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**

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

**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
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**

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

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/cm² 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**

<table>
<thead>
<tr>
<th>UV disinfection</th>
<th>UV-AOP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UV system capacity</strong></td>
<td>Assumed for the purpose of this sensitivity analysis: 2 MGD, 4 MGD, 8 MGD, 10 MGD</td>
</tr>
<tr>
<td><strong>Treatment target</strong></td>
<td>For non-potable reuse: total coliform 2.2 MPN/100mL; 5-Log polio virus reduction</td>
</tr>
<tr>
<td><strong>System components</strong></td>
<td>For potable reuse: 1,4-dioxane 0.5-Log reduction</td>
</tr>
<tr>
<td><strong>System components</strong></td>
<td>Closed-vessel UV system with LPHO lamps; H₂O₂ as oxidant or source of hydroxyl radical; sodium hypochlorite for hydrogen peroxide residual quenching</td>
</tr>
<tr>
<td><strong>Design UV transmittance (UVT)</strong></td>
<td>Membrane permeate 65%</td>
</tr>
<tr>
<td><strong>Design dose</strong></td>
<td>Microfiltration and RO permeate 95%</td>
</tr>
<tr>
<td><strong>Design dose</strong></td>
<td>NWRI guideline dose criteria: 80 mJ/cm²</td>
</tr>
<tr>
<td></td>
<td>$E_{EO}$ (electrical energy per order of contaminant removed) based dose criteria: 0.3 kWh/1,000gal/order; 5 mg/L H₂O₂</td>
</tr>
</tbody>
</table>

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.
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

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

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).
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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-H₂O₂ 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.
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:

- 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.

**Acknowledgement**

The authors gratefully acknowledge the engineers and scientists at Trojan Technologies, to name a few – Wayne Lem, Adam Festger, Alan Royce, Ted Mao and Scott Bindner – for providing UV technology and cost information in support of the analysis.

**References**


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

Determination Method for UV Output Power of Low-Pressure UV Lamps Under Various Application Conditions

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Abstract
The total UV output power of a UV lamp must be measured as the real UV output of the UV lamp and cannot be reflected only by measuring the relative UV irradiance in water with a radiometer. A stable value (or maximum value) of the total UV output of a UV lamp measured in a dark room is greatly different from and even uncorrelated to the UV output of the lamp within the corresponding temperature range in the actual water UV reactor. Therefore, it is not proper to evaluate the effect of a UV lamp in a water disinfection application, based only on data measured in air in a dark room. Indeed, it is necessary to measure the UV output power of the lamp under various water temperatures under conditions where the lamp power is adjustable.

This paper describes a method for determining the UV output power of a low-voltage UV lamp with a sleeve in a water reactor under certain water temperatures, based on assumptions that lamp voltage is correlated to UV output power under constant current and that the efficiency of UV lamp is the same if the lamp voltage under water testing is equal to that under air testing. Low-voltage UV lamps are abbreviated as UV lamp or lamp for short.

Keywords: Water disinfection, UV irradiance, relative UV irradiance, UV lamp power, UV lamp voltage

Introduction
Nowadays, ultraviolet (UV) disinfection technology is widely used for drinking water and wastewater treatment. The UV output power of a lamp in a UV reactor depends on the temperature of the water, which is a characteristic of low-pressure (LP) mercury lamps, so that different disinfection performances could be achieved at various water temperatures. Therefore, the relationship between the UV output power of a lamp and the water temperature in the actual disinfection system is a significant factor for optimization of the scheme of UV disinfection equipment disinfection safety guarantee. Moreover, the determination of the water temperature effect on the lamp output power is also helpful in saving the cost and energy consumption based on intelligent control of the UV lamp output power.

The stable value (or maximum value) of the UV output power of a lamp determined in the air by the conventional method is greatly different from that in an actual water disinfection reactor with routine water temperature. Therefore, such a measurement in air is not adequate to evaluate the effect of the UV lamp in the water disinfection application. However, until now, an appropriate method or protocol to determine the UV lamp output as a function of water temperature in a common UV reactor has not been available.

This study aims to propose a determination method of the UV output power under various water temperatures. In this method, the test UV lamp, sleeve and ballast are regarded as a whole. The impact of the water temperature, water flow velocity (e.g., 0.5 to 1.5 m/s) of the reactor, input power (e.g., constant current at 70% to 90% of maximum current) and life time of the test UV lamp (e.g., 5,000 to 12,000 hours) are discussed.

Materials and methods
Test lamps
A low-voltage amalgam lamp (Foshan-Comwin GZW250D19W-Z1554, arc length = 1.47 m) was employed as an example.

Method used in this study
As stated above, the proposed method for the determination of the UV output power of LP mercury UV lamps under various water temperatures is based on assumptions that lamp voltage is linearly dependent on the UV output power under constant current and that the efficiency of UV lamp is the same if the lamp voltage under water testing is equal to that under air testing. Four steps are involved in the method:
• determine the UV output power in air by using the conventional method (IUVA 2016);
• determine the relative UV irradiance of the lamp (with sleeve) in water under various water temperatures;
• determine the relative UV irradiance in air under various air temperatures;
• determine the transmittance of the sleeve under various water temperatures.

Results and discussion

Output power determination in the air

A dark room test refers to the UV lamp dark room test method proposed by the International Ultraviolet Association (IUVA 2016). The UV irradiance $E_0$ and the lamp voltage $U_0$ were measured when the temperature of the dark room was $25^\circ$C, the relative humidity was 65% and the ballast output current was held constant. The absolute UV output power $P_\Phi$ was calculated as per the Keitz formula (Eq. 1).

$$P_\Phi = \frac{20E\pi^2DL}{2\alpha + \sin 2\alpha}$$  \hspace{1cm} (1)

where:
- $P_\Phi$ = total UV lamp output power (W);
- $E$ = UV irradiance (mW/cm$^2$) as measured by using a UV radiometer;
- $D$ = distance (m) from the UV radiometer detector to the center of the UV lamp;
- $L$ = UV lamp arc length (m), namely the distance between the tips of the two filaments;
- $\alpha$ = the semi-angle (rad) between the radiometer detector and the UV lamp axis.

In the test, the UV lamp is placed at $D = 4$ m from the radiometer in a dark room, as shown in Figure 1. The determined photoelectric parameters are given in Table 1.

![Figure 1. Diagram of the dark room test.](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>Radiometer Irradiance $E_0$ (mW/cm$^2$)</th>
<th>Lamp Electrical Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage $U_0$ (V)</td>
<td>Current $I$ (A)</td>
</tr>
<tr>
<td>GZW250D19W-Z1554</td>
<td>0.614</td>
<td>163.1</td>
</tr>
</tbody>
</table>

The absolute UV output power ($P_\Phi$) is calculated as per the Keitz formula (Eq. 1).

The lamp efficiency $\eta$ is calculated as per Eq. 2.

$$\eta = \frac{P_\Phi}{P_E}$$ \hspace{1cm} (2)

where:
- $P_\Phi$ = the absolute UV output power (W);
- $P_E$ = lamp electrical power (W);

In this case, $\eta = 33.8\%$.

Water temperature characteristic test for a UV lamp in a sleeve in a water reactor

The measurement of the water temperature characteristic for a UV lamp in a sleeve is conducted in a water chamber where the water temperature range is from 5 to $40^\circ$C. The UV germicidal lamp and the radiometer detector are installed at the positions shown in Figure 2.

The middle of the quartz sleeve is connected to a round quartz plate, which in turn is connected to a transmitting sleeve; the radiometer detector is placed into the transmitting sleeve, which is perpendicular to the lamp to avoid test errors arising from flow fluctuations.

The distance from the surface of the radiometer detector allows the distance to the surface of the round plate to be at least 30 cm and thus the radiometer detector is always at $25^\circ$C or at the normal temperature environment.

The joint of the round plate is at least 30 cm away from the amalgam position to prevent any amalgam temperature variation in the actual application situation arising from weak variations of the thermo-mechanical field at the round plate.
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After the power supply is connected and the UV lamp is stable, the shutter over the radiometer detector is opened, and readings of the irradiance are read and the electrical parameters of the UV lamp, such as the lamp voltage, for the corresponding temperature are recorded.

Note that the principal function of the shutter is to provide thermal insulation to prevent effects on the precision of the radiometer arising from a temperature increase.

Test values for the lamp GZW250D19W-Z1554 in water are shown in Figure 3.

Figure 2. Diagram of the high-low temperature test chamber for evaluation of the UV output: (1) UV lamp; (2) sleeve; (3) positioning rack; (4) water chamber; (5) deionized water; (6) radiometer detector with shutter; (7) ballast connection, power supply and monitoring instruments.

Figure 3. UV lamp voltage for the lamp GZW250D19W-Z1554 vs. water temperature under conditions of constant current

Air temperature characteristic test

The UV lamp is placed in a high-low temperature chamber that is blackened. A draught fan operates in the chamber to make sure that the chamber temperature is uniform, but no airflow blows directly onto the UV lamp surface. The photoelectric parameters, including the irradiance at 4 m and the UV lamp voltage, are tested over the temperature range of 10-105°C under a constant current condition. The temperature at which the UV lamp voltage is equal or very close to U0 in the dark room test is obtained; then lamp voltage value can be equal or very close to the lamp voltage value under a specific water temperature by slightly adjusting the temperature, after which the corresponding irradiance and lamp voltage are accurately recorded. The radiometer detector is at least 0.3 m away from the UV lamp. This arrangement achieves thermal insulation by using a round plate that is made of quartz to guarantee that the radiometer detector is always at 25°C or at the normal temperature environment.

Figure 4. Diagram of the radiometer detector placement in the high-low temperature test chamber: (1) radiometer detector; (2) thermal insulating quartz plate; (3) UV lamp; (4) high-low temperature test chamber. Note that the function of the thermal-insulating quartz plate is to prevent any influence of high temperature on the precision of radiometer reading in the high-temperature test process.

The results of this test are shown in Figure 5.

Figure 5. UV lamp voltage vs. air temperature curve under conditions of constant current
$U_v$ is 163.1 V, and $P_\phi$ is 99.1 W in the dark room test. It can be seen from the temperature-lamp voltage curve (refer to the red line on the curve in Figure 5) that the temperature is 40°C when the lamp voltage is close to 163.1V. Namely, the lamp status in the high-low temperature chamber at 40°C is consistent with that in the dark room at 25°C. Its relative UV irradiance is $\eta_2(40°C)$. The UV output power $P_\phi = 99.1$ W is then substituted into the test form of the high-low temperature chamber at 40°C to calculate the UV output power for other temperatures:

$$P_\phi(T) = P_\phi(40°C)[\eta_2(T)/\eta_2(40°C)]$$  \hspace{1cm} (3)

where:

- $P_\phi(T) =$ the UV output power (W) at temperature $T$ in the high-low temperature chamber;
- $P_\phi(40°C) =$ UV output power at 40°C in the high-low temperature chamber (namely, corresponding to the UV output power $P_\phi =$ $P_\phi(40°C)$ measured in the dark room);
- $\eta_2(40°C) =$ relative irradiance of the lamp at 40°C in the high-low temperature chamber;
- $\eta_2(T) =$ is the relative irradiance at temperature $T$ in the high-low temperature chamber.

After comparing the experimental data of the water test to the experimental data of high-low temperature chamber, the following results were found:

The variation of the lamp status vs. water temperature in the range 5-40°C is close to that in the range 35-70°C in the high-low temperature chamber based on lamp voltage correspondence principle.

Lamp status measured at 10°C in water is consistent with that measured at 40°C in the high-low temperature chamber. Its relative UV irradiance is $\eta_1(10°C)$, UV output power $P_\phi(40°C) = 99.1$ W is substituted into the test form measured in water at 10°C to calculate the UV output power for other temperatures:

$$P_\phi(T) = P_\phi(10°C)[\eta_1(T)/\eta_1(10°C)]$$  \hspace{1cm} (4)

where:

- $P_\phi(T) =$ UV output power (W) of each point in the water temperature test;
- $P_\phi(10°C) =$ UV output power at 10°C in the water temperature test, corresponding to the UV output power of the lamp at the air temperature of 40°C in the high-low temperature chamber, namely

$$P_\phi(40°C) = P_\phi(10°C) = 99.1 \text{ W}$$  \hspace{1cm} (5)

where:

- $\eta_1(10°C) =$ relative irradiance of the lamp at 10°C in the water temperature test;
- $\eta_1(T) =$ relative irradiance of each point in the water temperature test.

The UV output power of each temperature point in the water temperature test is shown in Table S1 in the Supplementary section.

Comparing the test data in water with the test data in air, the UV output power $P_\phi$ in water corresponding to the UV output power $P_\phi$ in the high-low temperature chamber – temperature curve is shown in Figure 6.

![Figure 6. Curve of the lamp UV output power in water corresponding to the UV output power section in high-low temperature chamber. Blue curve: UV output power in high-low temperature chamber; red curve: UV output power in water reactor.](image)

Comparing the test data in the water with the test data in the air, the lamp voltage of the lamp in water corresponding to the lamp voltage of the lamp in the high-low temperature chamber – temperature curve is shown in Figure 7 on page 18.

The UV output power $P_\phi(T)$ in water is the output power of the lamp, but not the UV output power of the lamp with a sleeve in water.

**Determination of the sleeve transmittance**

A mercury UV lamp with the same dimensions was used for repeated tests to inspect the error and confirm the feasibility of test method. A sleeve transmittance test was conducted in an inte-
grating sphere. If the test is conducted by using an amalgam lamp, the test can be conducted after the lamp has cooled for a long time; the testing data are nearly the same, but it takes more time.

No matter whether a sleeve is used or not used, the mercury vapor pressure is very approximate and the electrical parameters are also very approximate when the lamp reaches the maximum UV irradiance. The transmittance of the sleeve was calculated as per the irradiance value $E_1$ or UV output power $P_1$ if a sleeve is not used, and the irradiance value $E_2$ or UV output power $P_2$ if a sleeve is used, namely, the transmittance $\eta' = E_2/E_1$ or $\eta' = P_2/P_1$.

The maximum irradiance value and the corresponding electrical parameters of the lamp whose length is equal to the length of the lamp GZW250D19W-Z1554 were tested as per the above method, in which $E_1 = 0.673 \text{ mW/cm}^2$, $E_2 = 0.604 \text{ mW/cm}^2$.

Thus, the transmittance of sleeve $\eta'$ is equal to $E_2/E_1 = 0.604/0.673 = 89.7\%$. The UV output power (W) in water $P_g(T)'$ is equal to $\eta' \times P_g(T)$ when a sleeve is used. The UV output power (W) of lamp GZW250D19W-Z1554 when a sleeve is used is shown in Figure 8.

**Summary of the measuring methods**

The measuring process for the determination of the UV output power for a UV lamp in a water reactor is divided into four steps. This is a serious process that involves optical parameter variation for each temperature point from the electric parameters of lamp under three measuring situations based on the electric parameter variation of lamp (constant current ballast, variation of lamp voltage) that substantially arises from variation of mercury vapor pressure of lamp. The method involves relatively stable experimental parameters and does not impose too rigorous requirements on the operator. One only needs to test involving relative values using a radiometer. The measuring results are relatively accurate.

This test mainly aims to calculate the absolute lamp output at each temperature point in a high-low temperature chamber and water based on UV irradiance (absolute value) tested in the dark room at 25°C in accordance with the lamp voltage variation (namely mercury vapor pressure variation) under different testing situations. The temperature performance of the lamp is shown in the lamp temperature-UV irradiance change curve in the high-low temperature chamber. In addition, temperature-UV irradiance change curve of the lamp in water can be reflected into the temperature-UV irradiance change curve in the high-low temperature chamber, so that one can judge the UV output in the water and judge if the lamp output performance is at the optimal working stage of the UV lamp. This method is different from non-comprehensive testing methods in that one only measures the UV output of the lamp in the dark room at 25°C, and the UV output of the lamp in a certain temperature range of water to judge the lamp performance.

Therefore, the proposed measuring method is applicable to accurately measure the UV output power of low voltage UV lamp under various water disinfection application conditions.
Determination Method for UV Output Power of Low-Pressure UV Lamps Under Various Application Conditions

Supplementary Material

Table S1. UV output power of each temperature point in the water temperature test

<table>
<thead>
<tr>
<th>Water temp $T$ (°C)</th>
<th>Lamp voltage $U_0$ (V)</th>
<th>Eff. value of lamp current $I$ (A)</th>
<th>Lamp Elec. Power $P_e$ (W)</th>
<th>Irradiance $E$ (mW/cm²)</th>
<th>UV Output Power $P_\Phi(T)$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>162.8</td>
<td>1.8</td>
<td>293.0</td>
<td>0.9622</td>
<td>98.1</td>
</tr>
<tr>
<td>10</td>
<td>163.1</td>
<td>1.8</td>
<td>293.6</td>
<td>0.9710</td>
<td>99.1</td>
</tr>
<tr>
<td>15</td>
<td>160.8</td>
<td>1.8</td>
<td>289.4</td>
<td>0.9680</td>
<td>98.8</td>
</tr>
<tr>
<td>20</td>
<td>157.7</td>
<td>1.8</td>
<td>283.9</td>
<td>0.9654</td>
<td>98.5</td>
</tr>
<tr>
<td>25</td>
<td>155.2</td>
<td>1.8</td>
<td>279.4</td>
<td>0.9460</td>
<td>96.5</td>
</tr>
<tr>
<td>30</td>
<td>152.3</td>
<td>1.8</td>
<td>274.1</td>
<td>0.9291</td>
<td>94.8</td>
</tr>
<tr>
<td>35</td>
<td>148.9</td>
<td>1.8</td>
<td>268.0</td>
<td>0.9086</td>
<td>92.8</td>
</tr>
<tr>
<td>40</td>
<td>146.9</td>
<td>1.8</td>
<td>264.4</td>
<td>0.8885</td>
<td>90.7</td>
</tr>
</tbody>
</table>

Justification that for a low-pressure ultraviolet lamp, the UV output and the mercury vapor pressure $P_{Hg}$ have a corresponding relationship, and that the voltage of such a lamp also has a corresponding relationship with $P_{Hg}$. The mercury vapor pressure ($P_{Hg}$) is proportional to the concentration of mercury atoms. When $P_{Hg}$ rises, the number of mercury atoms increases, the chance of collision with electrons increases, the opportunities of mercury atoms being excited to $6^3P_1$ state gradually increase, and thus the number of 253.7 nm ultraviolet (UV) photons gradually increases, as shown in curve A.

At the same time, when $P_{Hg}$ rises, the 253.7 nm UV photons emitted by mercury atoms impinge on adjacent mercury atoms to generate resonance absorption and re-radiate 253.7 nm UV photons. When the mercury concentration is high, frequent collisions cause mercury atoms exposed to 253.7 nm photons to be too late to produce resonance radiation. They collide with electrons or other atoms to produce other radiation, or the energy of the mercury atoms is lost due to collisions. In the center of the lamp, a large number of 253.7 nm UV photons generated by mercury atoms excited by electrons cannot radiate directly through the quartz tube. Through the mercury atomic layer, the number of 253.7 nm UV photons has a certain loss. The resonance emissivity can be seen in curve B.

When the lamp current is constant, only to change the mercury vapor pressure or ambient temperature, the lamp UV output as shown in curve C, there is an optimal mercury vapor pressure $P_{top}$, and the UV output power of the lamp is the maximum $P_{UV}$. The number of 253.7 nm photon

Analysis on relationship between lamp voltage and $P_{Hg}$: 1. The UV lamp voltage $V$ is given by:

$$V = V_{Ak} + EI$$

where:

$$E = \left(\frac{P_i + P_g + P_{UV} + P_{eur}}{e\mu e}\right)^{1/2}$$

$V_{Ak}$ = the cathode and anode voltage drop;
$E$ = the electric intensity in the positive column;
$l$ = the length of the positive column;

Electronic power consumption in the positive column includes:

$P_i$ = power consumption arising from electronic ionization, $W/e$, 1~10%,$P_g$ = power consumption arising from elastic collisions, $W/e$, 20%~30%,$P_{UV}$ = power consumption arising from 253.7 UV radiation, $W/e$, 50%~65%,$P_{eur}$ = radiant power consumption arising from other sources, $W/e$, 10%~20%;
and hence

\[ V = V_{Ak} + \left( \frac{P_i + P_g + P_{eur} + P_{eur}}{e\mu_e} \right)^2 l \]  \hspace{1cm} (3)

2. When the \( P_{Hg} \) is very low:

\[ P_{Hg} \uparrow \rightarrow P_{UV} \uparrow, \ P_{eur} \uparrow \rightarrow E \uparrow \rightarrow V \uparrow \]

hence, when \( P_{Hg} \) rises, the lamp voltage rises.

3. When the \( P_{Hg} \) is high:
   a. Note that

\[ P_{Hg} \uparrow \rightarrow P_{UV} \downarrow \]

but \( P_{eur} \) has risen only a little, whereas

\[ (P_{UV} + P_{eur}) \downarrow \rightarrow E \downarrow \rightarrow V \downarrow \]

The power source \( P_{UV} \) comprising the mercury atom 253.7 nm emission, is far greater than the other power sources \( P_{eur} \).

This means that when \( P_{Hg} \) rises, the lamp voltage drops.

b. An increase of \( P_{Hg} \) increases the ionization probability, improves the ionization rate at the given electron temperature, reduces the required electron temperature, and so reduces \( E \);

c. An increase of \( P_{Hg} \) increases the confinement of the resonant radiation, reduces the energy loss of discharge, and thereby reduces the (axial potential gradient) \( E \) required to maintain a given electron temperature.

A variety of long-term tests have been carried out on low-pressure UV lamps, when the lamp current is held constant, in which the UV output and the lamp voltage change with \( P_{Hg} \) changes. In every case, each test gives the same or very similar trends, namely that the lamp voltage is proportional to the total UV output. ■
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UV Industry News

**DOWA to be Ready for Mass Production of Deep Ultraviolet LEDs** – Dowa Electronics Materials Co., LTD, Tokyo, Japan, a subsidiary of Dowa Holdings Co., LTD., has developed a deep ultraviolet LED chip with a peak wavelength of 280 nm, output of 75 mW and dimensions of 1 mm x 1 mm. Since deep ultraviolet lights with a wavelength of 280 nm have a high-efficiency of disinfection, replacing the conventional mercury lamps with these LEDs enables facilities to be smaller and mercury-free. With other advantages, such as power saving, this product is expected to find new smart applications. This new product may provide light source manufacturers with greater flexibility for selection of package formats, such as lamps and chip-on-board (COB).

**TrojanUV to Supply UV for Ashbridges** – TrojanUV, London, Ontario, has been selected as the UV supplier for the disinfection conversion and upgrade project at the Ashbridges Bay Wastewater Treatment Plant in Toronto, Ontario. UV will become the plant’s main method of disinfection (replacing chlorine) and will provide broad-spectrum disinfection of a wide range of pathogens, including bacteria, viruses and protozoa. The design will consist of 12 channels, each containing two TrojanUVSigna banks of UV lamps. It is slated to be the largest TrojanUVSigna installation to date. For more information, visit www.trojanuv.com.

**New UV LED System Semray® Revolutionizes Industrial Curing Processes** – The new Semray® UV LED curing solution sets new standards in production flexibility and efficiency with its Plug & Play concept and powerful technologies. UV specialist Heraeus Noblelight, Hanau, Germany, recently launched a UV LED solution for industrial curing processes. The new UV LED system offers a Plug & Play concept for easy handling together with cooling systems and micro-optics that boost performance for optimal curing results. By minimizing stray light, the LED chip offers precise curing that is effective and efficient for a variety of applications. End users can achieve up to 30% faster curing times and cure at significantly higher working distances.

**Xylem Awarded UV Treatment Contract** – Xylem, Rye Brook, New York, a global water technology company, has secured contracts worth USD $4.8 million to supply state-of-the-art ultraviolet (UV) disinfection solutions to two major drinking water plants in the city of Columbus, Ohio. The energy-efficient UV technologies will be used to provide an additional treatment barrier for *Cryptosporidium* at the Dublin Road Water Plant (80 MGD plant) and Hap Cremean Water Plant (125 MGD plant) each providing safe, clean drinking water for Ohio residents.

**ZED GmbH Launches Lamp Add-On for Optimizing Amalgam UV Lamps** – Lamp dimming and fluctuation of water temperature can dramatically decrease the UV disinfection performance of UV systems. The UV output of low-pressure amalgam UV lamps is strongly dependent on temperature conditions. Small changes of environmental temperature could result in a drastic drop of UV output. The same effect can be noted if a lamp is operated in dimmed mode. The new electronic stabilization tool PPT (perfect performance tool) by ZED Ziegler Electronic Devices GmbH, Langewiesen, Germany, is able to compensate negative temperature influences. A lamp with PPT will produce the exact UV output for a wide range of water temperatures and particularly will increase performance in cold water. The UV output in dimmed mode is becoming much more predictable for the complete water temperature range. The PPT is directly mounted at the lamp. There is
no need for additional wiring or power source. For more details, contact info@z-e-d.com.

**AquiSense Technologies Announces Certification to ISO 9001** — A QuiSense Technologies, Erlanger, Kentucky, has been awarded the ISO 9001:2015 certification by the International Organization for Standardization. ISO 9001 places heavy emphasis on quality management system performance and ensures a company’s quality management system is strictly aligned with customer expectations. In addition to the announcement, A QuiSense’s PearlAqua water disinfection platform has been microbiologically tested in accordance with US EPA drinking water guidelines and has received certification in 2016 to NSF/ANSI 61 & 372 for materials safety. A QuiSense also complies with CE and RoHS standards for all its products.

**Allanson Announces UV Ballasts** — Allanson Lighting Technologies, Toronto, Ontario, has introduced its new line of 24VDC UV Ballasts that can be used for solar applications and remotely where access to electricity may be scarce. Allanson’s new 24VDC UV Ballast is available in 60 Watt and 80 Watt, 800 mA specifications. Arising from a direct need from the end user, Allanson is able to provide unique applications to meet increasing demands in a market where specific solutions were not always available. For more information, visit www.allanson.com.

**UV Systems Introduces New Company** — Consulting M&A Business Development LLC. announces the formation of UV Systems Consulting, a Renton, Washington-based business specializing in UV systems, UV lamps, UV ballasts, new UV technology advice, traditional UVC vs. future UVC with LEDs, and marketing. A high level of expert knowledge can be crucial when new products need to be designed, planned, pretested and validated. R&D, marketing and technical staff invests time, money and resources during new product development cycles so efficiency of these resources and added value is crucial. For more information, see http://uvlampconsulting.com or contact Karl Platzer at platzer@uvlampconsulting.com.

**Boston Electronics Updates Website** — Boston Electronics, Brookline, Massachusetts, has introduced its new website. The updated site will be a valuable resource for application and product information for IR and UV detectors and sources, quantum cascade lasers, photon counting solutions, thermal imaging and instrumentation. For more information, visit www.boselec.com.

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**At the 2017 IUVA World Congress** in September in Dubrovnik, Croatia, Oliver Lawal, president of IUVA, presented the biannual IUVA Achievement Awards. The awards committee included Jennifer Osgood, of CDM Smith; Jutta Eggers with DVGW; and Harold Wright, Carollo. More information will be presented in the Winter 2017 issue of *IUVA News*.

**Best Research Paper for the period 2015-17**
Sara Beck, University of Colorado; Harold Wright, Carollo; Thomas Hargy, Corona Consulting; Thomas Larason, National Institutes of Standards & Technology; and Karl Linden, University of Colorado. “Action Spectra for Validation of Pathogen Disinfection in Medium-Pressure Ultraviolet (UV) Systems.”

**Best Article in IUVA News for the period 2015-17**
Adel Haji Malayeri and Madjid Mohseni, University of British Columbia; Bill Cairns, Trojan Technologies; and Jim Bolton, Bolton Photosciences, “Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae.”

**Best Classic UV Paper**

**Best Conference Paper for the period 2015-17**
Gabriele Messina, University of Siena, “Novel UVC LED Approach for Disinfecting Contact Lenses.”

**UV Young Professional Award**
Li Si, Peking University

**Innovative Application of UV**
Kumiko Oguma, The University of Tokyo

**UV Light Award for Volunteer Recognition**
Ron Hofmann, University of Toronto

**Lifetime Achievement Award**
Regina Sommer, Medical University of Vienna
November
IUVA Singapore Symposium, Nov. 6-7
National University of Singapore
www.iuva.org/IUVAAsia

January 2018
2018 International Symposium on Potable Reuse, Jan. 22-23
Austin, Texas
www.awwa.org/conferences-education/conferences/potable-reuse.aspx

IUVA Corporate Members

Large organization
Calgon Carbon UV Technologies
Carollo Engineers, Inc.
CDM Smith Inc.
CH2M Hill Engineers, Inc.
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Heraeus Noblelight GmbH
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MWH Global
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Small organization
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Advanced UV Inc.
Allanson Lighting Technologies, Inc.
American Air & Water, Inc.
Aquifer Technologies
Atlantic Technologies Ltd.
Australian Ultra Violet Services (Operations) Pty Ltd.
Boston Electronics
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Foshan Comwin Light & Electricity Co., Ltd.
Funatech Co., Ltd.
GAP EnviroMicrobial Services Ltd.
GHD Consulting Services, Inc.
Gigahertz-Optik Inc.
Glasco UV LLC
Grundfos Water Treatment GmbH
HaiNing YaGuang Lighting
Elektroalco Ltd.
JenAct Ltd.

Medium organization
American Ultraviolet Company
atg UV Technology
Atlantic Ultraviolet Corporation
Berson UV-techniek
Bio-UV SA
et plus electronic GmbH
Hanovia Ltd.
HDR, Inc.
Nikkiso
Real Tech Inc.

SUEZ Treatment Solutions
Ushio America, Inc.
UV-technik Speziallampen GmbH
Water Technologies de Mexico
ZED Ziegler electronic Devices GmbH

Small organization
ABIOTEC Technologie UV
Advanced UV Inc.
Allanson Lighting Technologies, Inc.
American Air & Water, Inc.
Aquifer Technologies
Atlantic Technologies Ltd.
Australian Ultra Violet Services (Operations) Pty Ltd.
Boston Electronics
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GAP EnviroMicrobial Services Ltd.
GHD Consulting Services, Inc.
Gigahertz-Optik Inc.
Glasco UV LLC
Grundfos Water Treatment GmbH
HaiNing YaGuang Lighting
Elektroalco Ltd.
JenAct Ltd.

Light Progress
LIT Europe BV
NEDAP Light Controls
Neotec UV
NPO-ENT
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PWN
SA Water
S.I.T.A. SRL
SterilAir AG
ULTRAQUA
Ultra Violet Products (AUST) Pty. Ltd.
UV Dynamics
UV Guard
UV Superstore
Veolia Eau d’Ile-de-France
VGE International B.V.
Wonder Light Industry, Machinery, Electronic Products
(Zheng Shan) Co. Ltd.

Very small organization
Bolton Photosciences Inc.
Fresh Appeal USA, Inc.
Genicom
Peschl Ultraviolet
Silver Bullet Water Treatment
UV Care
UV Resources
DOWA

Deep UV LEDs for Disinfectant Applications

- High Performance and High Reliability 3535 SMD package.
- Bare Chip is Available

D Series
If=100mA
Po=11mW
Vf=5.2V
280nm

M Series
If=350mA
Po=25mW
Vf=5.4V
275nm

L Series
If=600mA
Po=45mW
Vf=6.0V
265nm

Available

Coming Soon

http://www.ultraviolet-led.com
http://www.dowa-electronics.co.jp

For more information, please contact "electronics@dowa.co.jp"

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