<table>
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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>8:30 AM - 9:00 AM</td>
<td>OPENING REMARKS</td>
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| 9:00 AM - 9:20 AM | DISINFECTION 1  
Real-time determination and long-term monitoring of UV fluence based on the “true” fluence rate detector without biodosimetry  
Menghai Li, Lyles School of Civil Engineering, Purdue University  
9:00 AM - 9:20 AM  
Challenges in UV Disinfection for Emergency Preparedness of Cryptosporidium  
Daniela Castañeda, MWH Global  
9:20 AM - 9:40 AM  
Mandatory UV Disinfection: New drops in Jordan’s water bucket to bolster limited water resources for the City of Irbid  
Jennifer Osgood, CDM Smith  
9:40 AM - 10:00 AM |
| 10:40 AM - 11:00 AM | DISINFECTION 2  
Algal DNA Damage Repair Kinetics Support MPN Evaluation of UV-Disinfected Ballast Water  
Natalie Hull, University of Colorado Boulder  
10:40 AM - 11:00 AM  
UV Compliance Simplified! New Validation Protocols  
Taco Brooks, Carollo Engineers  
11:00 AM - 11:20 AM  
UV Validation: Bridging the Atlantic Divide  
Mark Heath, Carollo Engineers, Inc.  
11:20 AM - 11:40 AM  
Not All Water Is Created Equal: The Effects of Water Characteristics on MS2 Stability and Dose Response  
Shawn Verhoefen, G&G EnviroMicrobial Services Ltd.  
11:40 AM - 12:00 PM |
| 10:00 AM - 10:40 AM | BREAK + EXHIBITS                                                                                                                             |
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| 11:00 AM - 11:20 AM | MUNICIPAL TREATMENT 1  
UV Procurement: A Holistic Approach To Provide Best Value  
Michael McWhirter, MWH  
10:40 AM - 11:00 AM  
Delivery of a Streamlined and Unconventional Dual-Vendor UV Design for a 100-Year Old Historic Drinking Water Treatment Plant  
Gabe Maul, MWH Global  
11:00 AM - 11:20 AM  
Designing a New UV Disinfection Facility for Multi-BARRIER Public Health Protection in Columbus, OH  
Chris Schulz, CDM Smith  
11:20 AM - 11:40 AM  
Welcome to the Modern Age: Upgrading Metro Vancouver’s Seymour Capilano UV Disinfection Facility  
Bryan Townsend and Ray Tarnai, Black & Veatch and Karen Tully, Metro Vancouver  
11:40 AM - 12:00 PM |
| 12:00 PM - 1:20 PM | LUNCHEON + EXHIBITS                                                                                                                            |
| 1:20 PM - 3:00 PM | PANEL DISCUSSION  
PANEL DISCUSSION: Fighting HAIs and MDROs with UV-C using Industry, Healthcare and Federal Collaboration  
1:20 PM - 3:00 PM |
| 3:00 PM - 3:40 PM | BREAK + EXHIBITS                                                                                                                            |
| 3:40 PM - 4:00 PM | DISINFECTION 3  
Pre-filtration UV disinfection - drivers, benefits and challenges  
Paul Swaim, CH2M  
3:40 PM - 4:00 PM  
The 254nm Myth - The Truth Behind Correct Wavelength Selection  
Saketh Thanneeru, AquiSense Technologies  
4:00 PM - 4:20 PM  
UV Disinfection of Viruses: Validation Protocols and Regulatory Perspectives in Ontario  
Bryan Townsend, Black & Veatch  
4:20 PM - 4:40 PM  
PERFORMANCE IS THE KEY: Substitution of a parallel UV system with a transversal staggered one to achieve disinfection goals. Recommendations in operation low UVT systems.  
Alvaro Irigoyen, CIEMSA  
4:40 PM - 5:00 PM |
| 3:40 PM - 4:00 PM | AOP & REUSE 1  
Moving from Non-potable to Potable Reuse: What Do We Do with UV?  
Chengyue Shen, HDR, Inc.  
3:40 PM - 4:00 PM  
Ultraviolet Sensors and Their Role in Monitoring of UV-Based Advanced Oxidation Treatment Systems  
Gordon Knight, Trojan Technologies  
4:00 PM - 4:20 PM  
Scaling UV AOP from Bench To Full-scale Implementation Using CFD-Based UV Dose Models  
Harold Wright, Carollo Engineers  
4:20 PM - 4:40 PM  
Making Sense of UV-Oxidation: EEO and Dose Together Ensure Potable Reuse Meets Goals  
Wayne Lom, Trojan Technologies  
4:40 PM - 5:00 PM |
<p>| 5:00 PM - 6:00 PM | RECEPTION + EXHIBITS                                                                                                                            |</p>
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<thead>
<tr>
<th>Time</th>
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<th>Title</th>
<th>Speaker(s)</th>
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<td>9:00 AM</td>
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<td>11:00 AM</td>
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<td>Effect of UV treatment on formation of disinfection by-products in chlorinated seawater swimming pools</td>
<td>Waqas Cheema, Technical University of Denmark</td>
<td>CAPITOL BALLROOM 2</td>
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<td>New Water Brew - Recycling Water for the Highest Purpose</td>
<td>Abigail Antolovich, Xylem</td>
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<td>Bacteria Inactivation via X-ray-induced UVC Radioluminescence: Toward In-situ Biofouling Prevention in Membrane Modules</td>
<td>Ezra Cates, Clemson University</td>
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<td>12:00 PM</td>
<td>LUNCHEON + EXHIBITS</td>
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<td>CAPITOL BALLROOM 1</td>
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<td>2:00 PM</td>
<td>INNOVATIONS &amp; APPLICATIONS 3</td>
<td>Experimental Evaluation of UV Reactors in Series</td>
<td>Yuri Lawryshyn, University of Toronto</td>
<td>CAPITOL BALLROOM 2</td>
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<td>Method for the determination of the UVC efficiency of a UV lamp mounted inside a UV reactor</td>
<td>James Bolton, Bolton Photosciences Inc.</td>
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<td>A Comparison of UV Transmittance Sensors at WWWTP's - Success and Challenges</td>
<td>Gary Hunter, Black &amp; Veatch</td>
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<td>Decomposition of Sucralose in a Small Scale 172nm Reactor</td>
<td>Jennifer Pagan, Aquiserres Technologies</td>
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<td>AOP &amp; REUSE 2</td>
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<td>Bill Sotirakos and Doug Wing, Carollo Engineers, Inc.</td>
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<td>Vacuum UV advanced oxidation of surface water and its impacts of biostability of the treated water</td>
<td>Majid Mohseni, University of British Columbia</td>
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<td>Enhancing Efficiency of UV Advanced Oxidation Processes via Iron Addition</td>
<td>Sydney Ulliman, University of Colorado Boulder</td>
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<td>The treatment of RO permeate for potable reuse using UV/chlorine advanced oxidation with low-pressure and medium-pressure UV lamps</td>
<td>Ron Hofmann, University of Toronto</td>
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<td>4:00 PM</td>
<td>DISINFECTION 4</td>
<td>Addressing variable UV/UV and peak flow challenges for existing wastewater UV disinfection with supplemental PAA</td>
<td>Michael Watts, Garver</td>
<td>CAPITOL BALLROOM 1</td>
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<td>UV sensor to monitor the low wavelength contribution to the dose of MP UV disinfection systems</td>
<td>Svend Kalminder, Xylem Services GmbH</td>
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<td>A simpler and more accurate method for collimated beam experiments</td>
<td>James Bolton, Bolton Photosciences Inc.</td>
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<tr>
<td>4:40 PM</td>
<td>BEST STUDENT PRESENTATION AWARD</td>
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TUESDAY, FEBRUARY 7, 2017

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BEST STUDENT PRESENTATION AWARD
4:40 PM - 5:00 PM
Moving from Non-potable to Potable Reuse: What Do We Do with UV?

Chengyue Shen, HDR, Inc.

Abstract: To address the increasing water shortage, especially in California and a few other southern states of the United States, the current trend in water reuse is moving towards potable reuse, either direct or indirect, to maximize the potential of all available water resources. Significant efforts have been made among water industry and water agencies on defining the guidelines and criteria needed for potable reuses 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 destruct the persistent chemical contaminants.

UV technologies have been widely applied in disinfection for non-potable water reuse in compliance with the California Water Recycling Criteria (Title 22). With the interests in potable reuse, it is a natural reaction for most water reclamation 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 required in a UV-AOP process, i.e., less than 100 ml/cm2 versus hundreds or often over 1,000 ml/cm2 for UV-AOP. This imposes a significant challenge on how to upgrade or expand the currently installed UV systems, which were originally sized for disinfection, to meet the requirement for UV-AOP.

This paper presents the discussions on how to prepare a non-restricted reuse plant for non-potable reuse UV-disinfection today while bearing the potential capability of future expansion for potable reuse using UV-AOP. The following aspects will be presented around a successful show-case application:

• Regulatory road map: Upgrade of an existing UV-disinfection system to an UV-AOP is one of the viable and cost-effective approaches to keep the facility in compliance with the changing regulatory requirements.
• Technology applicability: With particular 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.
• Implementation approach: Existing system upgrade or facility planning needs to consider the significant difference of UV implementation in terms of treatment target and design criteria for non-potable vs. potable reuse.
• Field demonstration/validation: The UV-disinfection system for non-potable reuse is typically selected and designed with UV technology from California DDW published list. Field validation after installation is required for UV-AOP.
Ultraviolet Sensors and Their Role in Monitoring of UV-Based Advanced Oxidation Treatment Systems
Gordon Knight, Trojan Technologies

Abstract: Ultraviolet sensors are devices used to monitor and control the UV irradiance within a water treatment system. Since the kinetics of photochemical reactions depends directly on the UV fluence rate within a system, measurement of irradiance monitors this critical reactor variable. Physical factors in the reactor such as changes in lamp output, lamp sleeve ageing and fouling, as well as water transmittance can all be monitored by UV sensors. Sensor types used for monochromatic and polychromatic lamp systems will be reviewed. For UV disinfection systems, it is common practice to determine the validated UV dose dependence on UV sensor signals, as well as other variables. The prospects and challenges in extending this concept to contaminant treatment will be discussed in the light of the similarities and differences between UV disinfection and contaminant treatment processes.

The use of sensors in contaminant treatment offers unique opportunities to improve monitoring and control, such as for the monitoring of lamps in high transmittance waters typical in water reuse applications. The challenges in monitoring reflected UV radiation will also be considered. Possible integration of these features into a sensor monitoring and control system for contaminant treatment will be discussed.

Making Sense of UV-Oxidation: EEO and Dose Together Ensure Potable Reuse Meets Goals
Wayne Lem, Trojan Technologies

Abstract: W.Lem* and A.Festger

The use of UV irradiation combined with hydrogen peroxide for the destruction of trace contaminants in municipal wastewater after microfiltration and reverse osmosis has been accepted for indirect potable reuse (IPR) and direct potable reuse (DPR) schemes in the United States. The key driver for the growing trend in reuse results from the serious water scarcity and water stress issues many parts of the world are facing today.

The implementation of UV/peroxide systems for IPR and DPR applications require an accurate and fail-safe monitoring and control system to safeguard public health. The figure-of-merit for UV/AOP systems is the Electrical Energy per Order (EEO)1 which is defined as the electrical energy in kilowatt-hours (kWh) needed to degrade a contaminant by one order of magnitude (90%) in a unit volume of polluted water. Decades ago, UV/AOP systems were controlled using EEO, primarily for non-potable wastewaters such as groundwater remediation or industrial wastewater treatment – where public health was not of paramount importance. However, today, given that water reuse quality directly impacts public health and public perception, the monitoring and controls of a UV/AOP system needs to be advanced, accurate and fail-safe to address this.
A methodology will be presented to accurately control UV/AOP systems whereby the algorithm incorporates both the EEO and UV dose of the reactor using real-time flow, UV transmittance and lamp output signals combined with the contaminant kinetics to deliver the required removal of a contaminant. Performance data from several full-scale IPR systems in California, USA, will be presented to show the correlation between actual and predicted results. This methodology produces increased accuracy compared to traditional dated methods and furthermore, provides an empirical approach for on-site verification of reactor performance for the end-user.

**Scaling UV AOP from Bench To Full-scale Implementation Using CFD-Based UV Dose Models**  
Harold Wright, Carollo Engineers

Abstract: UV AOP is used in drinking water applications for seasonal T&O reduction, and used in drinking water and potable reuse applications for continuous reduction of NDMA and micro-pollutants. UV AOP often uses H2O2 to generate hydroxyl radicals. Recent research has shown the effectiveness of UV AOP using chlorine for potable reuse applications. Other research has shown that that MP UV and naturally present nitrate can promote AOP.

One challenge implementing UV AOP is scaling bench results obtained using a collimated beam or fully mixed batch reactor to full scale, in part because many theoretical UV AOP models are not based on UV dose. In this work, UV dose based models are presented for LP and MP UV AOP. Data is shown comparing model predictions and measured data with a range of contaminants (MIB, geosmin, 1,4-dioxane, TCE and PCE), and a range of water qualities (pH, alkalinity, TOC). With MP UV light, the models use UV dose for photolysis and AOP defined as an integrated dose from 200 to 400 nm weighted by the action spectra of the target, whether that be the contaminant in the case of photolysis or the oxidant in the case of AOP. Model predictions are presented with pilot LP and MP reactors where the UV dose has been determined as a UV dose distribution using CFD-based UV dose models. The role of UV AOP models for optimizing the design and operation of full scale AOP systems is discussed

**DISINFECTION 1**

Real-time determination and long-term monitoring of UV fluence based on the “true” fluence rate detector without biodosimetry  
Mengkai Li, Lyles School of Civil Engineering, Purdue Universi

Abstract: Conventional methods for monitoring and validation of photoreactors are based on measurements of the nominal fluence (or dose) delivered by the reactor. The current standard for these measurements is biodosimetry, which yields a
single-valued fluence measurement to define the behavior of the system. While biodosimetry has the benefit of providing operators and regulators with a physical measurement of the nominal fluence delivered by a system, it suffers from important shortcomings, including the inability to quantify the fluence distribution and conduct these measurements in real time.

The nominal UV fluence delivered by a reactor depends on two factors. One is the status of the lamp/sleeve system, such as the quality and operational status of the lamp and ballast, and the transmittance of the lamp tube and quartz sleeve. The second factor is the combination of the optical field (or fluence rate [FR] distribution) and the fluid field.

The micro-fluorescent silica detector (MFSD) was developed with merits of high stability, extremely fast response, and very small volume, and thus is an ideal sensor for monitoring of UV reactors. It is also important to note that it is the only “true” FR detector and the measured FR value is an accurate representation of the FR definition which can be directly compared with numerical simulation results without any angle-response correction.

Based on measured FR values by MFSD installed at an appropriate position in the reactor chamber, as well as routine parameters including the UVT value and flow rate, the real-time status of lamp and sleeve system could be determined for a running UV reactor. Moreover, when combined with a fluence calculation model (including the fluence rate distribution model and fluid dynamics model), the real-time mean or minimum UV fluence could be obtained without biodosimetry. In addition, a field study during half a year was also carried out to evaluate the feasibility of the method. This study proposes a new real-time UV fluence determination and long-term monitoring method based on the “true FR detectors” (i.e., MFSDs), which could enhance the security of the UV disinfection.

**Challenges in UV Disinfection for Emergency Preparedness of Cryptosporidium**

Daniela Castañeda, MWH Global

Abstract: Ultraviolet (UV) disinfection systems are commonly designed with various assumptions including source water quality trends. Influent variations are already a challenge, in particular when water treatment plants (WTPs) are adjacent to their source and can experience a flooded torrent’s upset water quality. How does a WTP adjust, especially when the emergency conditions force it to utilize the only available source- a flooded river?

That was the situation for the City of Minot, North Dakota in 2011 when the Minot WTP couldn’t meet effluent disinfection limits after experiencing a flood with high Cryptosporidium concentrations. The City began emergency preparedness with a new UV disinfection system as part of the Flood Hazard Mitigation Project to be able to meet the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) under flooding conditions. LT2’s requirements for Cryptosporidium inactivation already present a potential risk to public health protection due to action spectra difference between pathogens and surrogates. This challenge was further augmented since the
limited sampling performed during the 2011 flood didn’t include Cryptosporidium or UVT. Additionally, the WTP had experienced feed power quality issues that could significantly increase the project’s cost to support the performance and reliability of a UV-based emergency system.

This presentation will focus on how the UV system’s expected limited operation affected the project’s approach to balance cost-efficiency and assured performance. It will review the design strategy to collaborate with local and state regulators, prioritize emergency considerations, and the manufacturer’s warranty. The presentation will also summarize flooding systems input from multiple UV vendors, as well as reference floodwaters projects. All of these points are expected to meet Minot’s future floodwater disinfection demands while being able to meet the City’s budget, and provide reliable criteria selection references to help UV disinfection be a better supported alternative for future floodwater projects.

**Mandatory UV Disinfection: New drops in Jordan’s water bucket to bolster limited water resources for the City of Irbid**

*Jennifer Osgood, CDM Smith*

Abstract: Water scarcity is a global environmental challenge, and for Jordan is one of the country’s largest environmental challenges. Due to normal increases in population growth within the country along with recent influxes of refugees, Jordan’s limited natural water resources are unable to support sustainable water management practices. The Northern Governorates region has been hit hard which has the Jordanian authorities struggling to keep up with the water demand, while the country continues developing solutions to increase its water supply. Much of the new water sources required to supply Jordan’s basic water needs will need to originate outside of Jordan’s boundaries. Jordan has begun to use highly treated wastewater effluent for irrigation and repurposing water previously used for irrigation to supply population consumption needs. Even with these changes, the Northern Governorates are forecasted to require more potable water than is available from the current groundwater supply. The King Abdullah Canal (KAC) has been identified as one source to provide additional supply for Jordan. The KAC obtains water from Lake Tiberias in Israel and the Yarmouk River whose headwater is in Syria. Terms of a recent international agreement with Israel provide additional water rights from the canal, which are proposed to partially meet the water needs of the City of Irbid in the Northern Governorates. The KAC provides water for irrigation as well as supplies most of the potable water supply to the capital city of Amman. Water quality within the KAC can be challenging to treat. Run-off and flushing events can cause very quick changes in water quality with turbidity levels rising into the thousands of ntu while the warm environment and ample nutrients encourages algae growth. Levels of disinfection byproduct precursors, bromate, and taste & odor present additional challenges. The Ministry of Health has classified the KAC as Category 3 water, which requires a minimum level of treatment as defined by Jordanian Water Standards including UV disinfection and specified inactivation for pathogens. The new water treatment facility will supply 30 million cubic meters
per year (MCMY) of treated water with multi-barriers to effectively treat most water quality events, thereby limiting the duration that the facility has to be flow de-rated or shut down all together. The treatment facilities will include presedimentation, conventional pretreatment, GAC adsorption, filtration, UV and free chlorine disinfection, residuals treatment and washwater recovery to maximize available water resources. The facility will operate continuously at its design capacity. Should additional water be allocated in the future, the design considers a facility expansion to 45 MCMY. The facility initiated by the Ministry of Water and Irrigation and the Water Authority of Jordan in collaboration with USAID is addressing a portion of the country’s urgent need for water supply as part of the Government’s Water Sector Strategy.

DISINFECTION 2

Algal DNA Damage Repair Kinetics Support MPN Evaluation of UV-Disinfected Ballast Water
Natalie Hull, University of Colorado Boulder

Abstract: Aquatic invasive species and pathogens can be transported and discharged by ships in ballast water used to stabilize their loads. To mitigate these effects, in 2012 the US Coast Guard (USCG) and recently the International Maritime Organization (IMO) adopted pathogen and size-delineated discharge performance standards for ballast water management. Compliance can be achieved through installation of an approved ballast water treatment system (BWTS). Approval of BWTS efficacy can be attained from IMO using various enumeration methods, but USCG approval requires enumeration using stains that detect membrane disruption for organisms in the 10 – 50 µm size fraction. These stains cannot detect DNA damage, which is the primary mechanism for ultraviolet (UV) disinfection. However, culture-based methods such as most probable number (MPN) could be appropriate for evaluating technologies with varying mechanisms of inactivation, and could provide a conservative estimate of UV treatment efficacy because incubation allows potential DNA repair and regrowth to occur. To test this hypothesis, UV-induced DNA lesions were quantified by ELISA in Tetraselmis suecica control samples and UV-treated samples cultured under various MPN conditions over time. These ~10 µm marine algae demonstrated significant DNA repair within the first 6 hours of MPN incubation, and repair was insensitive to varying light or nutrient conditions. Because culture conditions allow DNA repair much more rapidly than the typical 14-day incubation, MPN enumeration accounts for repair that could increase viable cell concentration. These molecular results support using culture-based enumeration as a conservative method to validate UV and other BWTS technologies.
UV Compliance Simplified! New Validation Protocols

Traci Brooks, Carollo Engineers

Abstract: The United States Environmental Protection Agency (USEPA), in conjunction with the Cadmus Group and Carollo Engineers, has initiated a study to develop a simplified approach to validation of UV reactors used for small and medium size drinking water systems to meet the virus inactivation requirements of the Ground Water Rule (GWR). The scope of the project was to evaluate validation testing protocols for low pressure high output (LPHO) and medium pressure (MP) UV systems, evaluate simplified dose monitoring approaches, and in the case of polychromatic MP UV systems, evaluate the implications of the germicidal impacts of low wavelength light on virus inactivation.

The testing for the LPHO and MP UV reactors showed the ability to predict 4 log inactivation of adenovirus using only MS2 phage and using the combined variable, S/S0/Q/DL, where S/S0 is the relative lamp output at low or high wavelengths, Q is the flowrate, and DL is the UV sensitivity of the microbe defined as the UV dose required per log inactivation. The MP UV testing utilized a new low wavelength UV sensor that had a response range from 200 to 240 nm along with a standard ONORM-compliant UV sensor with a response range from 240-290 nm. This new sensor along with the application of high and low wavelength action spectra correction factors (ASCF) and the combined variable helped to develop an equation that can be used to predict Cryptosporidium and adenovirus inactivation that fully takes advantage of low wavelength benefits.

The results are being used to develop a new protocol document that will include direction on using 4 log MS2 inactivation to predict 4 log inactivation of adenovirus using the combined variable, specifications for low wavelength UV sensors, and methods for calculating and applying low and high wavelength ASCFs for MP UV reactors. This document will also include better defined UV dose monitoring equations, simplified application of the reduction equivalent dose (RED) bias factors, a well-defined validated range, and well-defined QA/QC bounds for validation microbes.

This presentation will go through the proposed new methods for UV validation with support from data collected during this project and previous validations.

UV Validation: Bridging the Atlantic Divide

Mark Heath, Carollo Engineers, Inc.

Abstract: Ultraviolet disinfection for drinking water treatment has gained worldwide acceptance over the past two decades with its routine use in Europe extending decades earlier. Regulatory approval is governed by different organizations in different parts of the globe. In Europe, regulatory acceptance is primarily governed by the German Association for Gas and Water (DVGW) and the Austrian Standards Institute (ONORM), while in the United States the US Environmental Protection Agency (EPA) published the 2006 UV Disinfection
Guidance Manual (UVDGM) for compliance with the standards of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

To demonstrate performance of UV disinfection equipment for regulatory acceptance, full-scale validation testing is required. Validation techniques differ between the various regulatory jurisdictions, and to gain global regulatory acceptance, UV equipment vendors must perform costly validation testing to meet the requirements of each. This often means vendors must ship UV equipment to more than one of the handful of validation test facilities worldwide, incurring substantial costs associated with installation, functional testing, biodosimetry testing and data analysis procedures stipulated by each regulatory jurisdiction. With the cost of validation ranging from $50,000-$100,000 and in some cases substantially more for a single validation, there is a significant barrier for UV vendors achieving global regulatory acceptance of their equipment. In addition, for large capacity UV equipment, there are few options for validation facilities capable of the required flow rates for testing.

Recent cooperative efforts between Carollo’s Portland UV Validation Facility in Portland, OR, USA and the DVGW TZW testing facility in Karlsruhe, Germany allowed a major UV vendor to test one of their higher capacity UV units under both US EPA UVDGM and DVGW testing protocols. The benefits of this cooperative effort allowed the UV vendor to achieve dual validation at a maximum flow capacity not achievable by the German test facility, at the same time realizing substantial cost savings by testing only at one facility. By the end of 2016, further cooperative testing will be conducted on four UV reactors from two UV vendors at the DVGW TZW test facility under the US EPA UVDGM protocols. This will allow the two European vendors to conduct testing locally, thus reducing the costs associated with supporting validation testing in the United States, while achieving certification under US EPA UVDGM protocols.

This presentation will discuss the primary differences between various UV validation protocols and UV dose monitoring philosophies as well as summarize the cooperative testing conducted to date and that proposed moving forward that will provide significant cost and time saving benefits to the UV industry.

**Not All Water Is Created Equal: The Effects of Water Characteristics on MS2 Stability and Dose Response**

*Shawn Verhoeven, GAP EnviroMicrobial Services Ltd.*

Abstract: Ultraviolet (UV) reactors for water disinfection typically have their performance claims verified using a bioassay. This involves running water spiked with a surrogate microbe, such as MS2 bacteriophage, through the system under a variety of flow, UVT and system power conditions, and measuring the reduction of the surrogate concentration upstream to downstream. The characteristics of the water are one condition, specifically in small and bench scale validations that are typically ignored, but one that can drastically impact the results obtained during the validation. We have shown that some water may make it appear as if UV light at 254nm is very effective at disinfecting MS2, but a portion of this reduction can be attributed to the water itself, and not the exposure to UV light. The only way this
would be detected as an issue when validating a UV system would be by determining the dose response, using a collimated beam, of the influent, surrogate spiked, water. If the resulting dose response curve falls within the established limits for the surrogate being tested, then the performance claims for the validation could be verified. Also, it isn’t acceptable to simply use the dose response curve that falls outside of the established limits, as we have shown that this inactivation may not be repeatable and can vary greatly over repeat exposures. This work shows how important it is to perform collimated beam testing with every validation and water type used and to not use quality control dose response curves as a means of assigning a dose, to ensure surrogates used for validation have established limits (whether lab established or published), and to ensure that variations in source water quality are captured in the collimated beam testing, such as with each batch of water used.

**DISINFECTION 3**

**Pre-filtration UV disinfection – drivers, benefits and challenges**

*Paul Swaim, CH2M*

Abstract: The use of UV disinfection for primary disinfection continues to grow as more municipalities are required to improve or expand their treatment capabilities where budgets, site space, and risk management cannot be adequately addressed with additional chemical disinfection. Typically, UV disinfection is implemented after filtration in conventional or membrane filtration facilities, or in combination with chemical disinfection when filtration is not mandated. However, there are cases where UV ahead of filtration can be cost effective and provide similar treatment reliability. This paper reviews the implementation of UV disinfection (both LPHO and MP) prior to filtration in three different filtration facilities including the 400 ML/d Lakeview WTP Phase 2 Expansion for the Region of Peel, the 38 ML/d Lakeshore WTP for the Town of Innisfil, and the 615 ML/d R.L. Clark WTP for the City of Toronto. The following issues will be discussed: economic drivers, such as reduction in constructed footprint and costs by retrofitting existing facilities vs. building green field facilities; water quality risks and regulatory approvals; and technical and operational issues, such as construction in tight spaces, and developing UV dose-response curves for operation at higher turbidities without compromising disinfection capabilities.

**The 254nm Myth – The Truth Behind Correct Wavelength Selection**

*Saketh Thanneeru, AquiSense Technologies*

Abstract: The 254nm Myth – The Truth Behind Correct Wavelength Selection

[Saketh Thanneeru, Oliver Lawal, Jennifer Pagan, Jim Cosman. AquiSense Technologies, 4400 Olympic Blvd, Erlanger, KY 41018]
ABSTRACT:
Over the past three decades Ultraviolet (UV) technology has had a meteoric rise in the water disinfection market, as a result of a combination of lower costs, pathogenic resistance to Chlorine (e.g. Cryptosporidium), and the potential of harmful byproduct generation associated with chemical disinfection. UV light within a practical wavelength range of 180–280nm, or UV-C, is applied in disinfection applications. Historically we have had access to this range primarily through mercury vapor lamps, the majority of which are of the Low Pressure type, emitting a monochromatic output at 254nm. Over time, the entire UV-C range has often been given less importance and the emphasis has been on that accessible wavelength of 254nm. It is sometimes lost among process designers that this wavelength is not the most optimal amongst those within the germicidal range, but the only practical option available – thus raising it to a mythical status. The effectiveness of a particular wavelength depends on the amount of light a pathogen is able to absorb at that particular wavelength. There are many bench scale studies on pathogens showing different absorbance levels at different wavelengths, and, 254nm is never shown as the most effective. The optimal wavelengths vary according to the pathogen, but typically fall in the 260 - 270 nm range.

With the advent of deep UV LEDs, we have the option to choose specific wavelengths in UV-C range. The specific wavelength in the range and the absorption levels of the pathogens become important for efficient designing of UV systems targeting specific pathogens. This paper will outline the impact of not believing the 254nm myth and will discuss the overall benefits derived by the design flexibility (i.e. ability to select discrete wavelengths) enabled by the introduction of this new UVC source.

UV Disinfection of Viruses: Validation Protocols and Regulatory Perspectives in Ontario
Bryan Townsend, Black & Veatch

Abstract: Ultraviolet (UV) light disinfection is a common treatment process in municipal drinking water systems in Ontario. Ontario’s position has been to credit UV systems for Giardia, Cryptosporidium, and virus inactivation. Virus inactivation credit assignment is based on the dose-response data of pathogenic viruses other than adenovirus. Municipal residential drinking water systems are currently receiving 2 log virus credit at a surrogate reduction equivalent dose (RED) of 20 mJ/cm2 if it is part of a multi-barrier disinfection strategy or 40 mJ/cm2 if UV is employed as the sole treatment barrier. Treatment for adenovirus is only required for source waters that may be influenced by sewage and require chemical disinfection.

While UV systems must be validated in accordance with industry-standard protocol, including the UV Disinfection Guidance Manual (UVDGM), no standardized dose requirements or guidance is included for any pathogens other than Cryptosporidium, Giardia, and adenovirus. As a result, applying the UVDGM and determining a
validated dose for the sizing and operation of UV systems for the disinfection of alternate pathogens is problematic.

The Ontario Ministry of the Environment and Climate Change, in collaboration with Black & Veatch, are currently working on a project to develop standardized dose requirements and procedures to calculate validation factors for rotavirus. Phase 1 of the project included a literature review to identify existing sources of information, analysis of existing data, and identification of information gaps. Three key areas where information was required were identified including (a) standardized UV dose-response; (2) RED bias factors; and (3) action spectra bias correction factors. Phase 1 has been completed and the project team is developing plans to proceed to Phase 2, which will address the identified information gaps and develop a guidance document for rotavirus inactivation.

**PERFORMANCE IS THE KEY: Substitution of a parallel UV system with a transversal staggered one to achieve disinfection goals.**

**Recommendations in operation low UVT systems**

*Alvaro Irigoyen, CIEMSA*

Abstract: In 2010, (OSE), the Uruguayan water and sanitation company, secured a contract for the construction of a new sewage system for the cities of Maldonado and Punta del Este. Completed in 2012, it’s based on an improved primary treatment plant with an offshore outfall of 1100 meters, and includes a UV disinfection system. Its maximum capacity is 4,960 m3/h. The UVT of the influent to the UV systems is less than 40 percent. The original solution was, Wedeco TAK55UV system with two banks in series of 11 modules and 18 lamps (LPHO) in each module with parallel lamps design. Following commissioning, the operators found that the technology originally selected did not perform in line with expectations of reduction, 3 log (99.9%) reduction in fecal coliform numbers. Working together, the author with XYLEM-WEDECO engineers, studied the equipment and its installation. Having established a clear understanding of the parameters of the system, the Xylem team was able to recommend a 'best fit' solution which would ensure optimum efficiency and reliability - Wedeco DuronUV system consists of 216 lamps in 1 channel (18 modules -12 lamps each, installed in six banks) transversal- staggered design. This study examines two disinfection system designs and provides recommendations on optimizing system design with low UVT influent. After one year of working with each equipment (parallel first and inclined now) we are in order two compare the design and the efficiency of each one and their PROS AND CONS.
Next Generation UV Disinfection – How UV-C LEDs Will Enable New Applications
Molly McKain, AquiSense Technologies

Abstract: Authors: Molly McKain, Oliver Lawal, Jennifer Pagan, and Jim Cosman

Mercury-vapor UV-C lamps were commercialized in the 1970s and became the UV technology of choice. The industry steadily grew for the next 40 years, but growth has drastically slowed in recent years. This paper explores how UV-C LED systems enable the development of new applications and thereby enhance UV market growth. The presentation will review current and anticipated UV-C LED applications as well as proposed revisions to NSF 55.

Mercury-vapor lamps have long been the only viable UV-C generating option, but UV-C LED systems can be produced without the heavy metal. Innumerable medical UV-C opportunities previously inaccessible due to hospitals limiting mercury are now achievable by UV-C LEDs because they eliminate the risk of mercury contaminated water, caused by vapor lamp failure, reaching patients.

UV-C LED systems have a footprint 75% smaller than comparable mercury-based systems and turn on/off instantaneously, making them ideal for Point of Use applications where UV technology has formerly conceded such as behind shower heads and inside refrigerators. UV-C LED systems are also very robust and are being considered for multiple aviation and space-based projects that fragile mercury systems would be ill-suited for. Some LED systems have already earned NSF 61 certification.

UV-C LEDs are enabling the expansion of UV technology, but it is important to recognize they are not necessarily an exact replacement for mercury-vapor lamps. The development of UV-C LED based system requires a paradigm shift in approach to design because UV-C LEDs are far less efficient than mercury-vapor lamps as an individual light source. However, if LED systems employ novel techniques to compensate for this inefficiency and deliver an adequate disinfecting dose, they become a viable option for expanding the UV market. Existing UV validation protocols must also be modernized to enable the timely utilization of these systems.

Best Practices In Measuring the Power Output of UVC LEDs
Rajul Randive / Leo Schowalter, Crystal IS

Abstract: The UVC LEDs continue to gain traction with on demand disinfection applications. During discrete diode testing, customers may often see a difference in the measured light output compared to the output specified on the manufacturer’s data sheet. At the present time, guidelines for reliable, standardized measurements
do not exist even though such standards would provide customers with a way to compare UVC LEDs offered by different manufacturers and ensure accurate repeatable optical property measurements. Individual UVC LED manufacturers need to develop techniques to accurately measure and represent the optical properties of their products. In this paper, we discuss an approach for manufacturers and customers to measure the UVC LED output with a pulse mode method. The objective is to reproducibly measure the power of the device in a way that minimizes the impact of heat generation during product measurement without necessitating the attachment of a thermal management system and still captures a power that is representative of continuous wave operation with thermal management. A general methodology will be introduced with examples on the impact of pulse length on the measured power output. Implications of measurement equipment and calibration processes will also be presented.

A UV-C LED to contrast Acanthamoeba keratitis caused by contact lenses
Gabriele Messina, University of Siena

Abstract: The diffusion of UV-C LEDs for disinfection of surfaces and fluids is rapidly increasing because of their large advantages with respect to mercury lamps and the progressive reduction of market entry barriers and costs. For low-power irradiation of small and well exposed surfaces, UV-C LEDs are already effective. The UV-C LED disinfection of contact lens (CLs) is a fascinating challenge because the UV-C dose must be calibrated as a suitable tradeoff between the possible deterioration of lens polymers and the occurrence of keratitis, especially that caused by Acanthamoeba, very dangerous for sight and not yet totally eradicable by any chemical agent.

In the present study we tested the disinfecting power of a UV-C LED (275 nm peak wavelength) of about 3.0mW power, applied to commonly-used monthly CLs. Each CL was immersed in 1 ml of phosphate buffered saline (PBS) contaminated with 45 units (trophozoites and cysts) of Acanthamoeba. CLs were then irradiated in 1 ml of contaminated PBS for 4 hours; then we placed on Petri dishes 0.1ml (from each case) and CLs (both the sides); comparisons with matched controls were made.

Disinfection was considered effective only if Acanthamoeba was not detected from both lenses and the hydrating liquid.

Acanthamoebas were all killed, in both operating conditions, indicating that UV-C rays were able to cross the CL thickness.

More tests will be carried out (in progress) to assess the damage from prolonged UV-C LED light on various types of CL polymers, to organize possible countermeasures.
MUNICIPAL TREATMENT 1

UV Procurement: A Holistic Approach To Provide Best Value
Michael McWhirter, MWH

Abstract: The City of Columbus, Ohio, Department of Public Utilities (DPU), Division of Water (DOW), intends to install Ultra-Violet (UV) equipment for disinfection at its Hap Cremean water plant (HCWP). The project has completed the preliminary design phase to frame the project and during late 2016 is procuring the UV equipment. Detailed design will be conducted during 2017 in collaboration with the successful UV vendor. The HCWP installation will be an instillation of UV reactors on individual filter outlet pipes to avoid significant civil and structural construction at the site and greatly minimize the overall cost of implementing UV at the facility. To ensure the UV equipment procurement will provide the overall best value for the City the process will include evaluation of significantly more than the simple purchase cost of the UV. Life-cycle costs will be determined for replacement of spare parts and provision of consumables including electricity for running the equipment. This lifecycle evaluation is somewhat unique due to the installation of a large number of UV reactors on individual filter outlet pipes and the somewhat unusual turn-down scenarios that this results in.

The impact of the UV equipment on the wider facility will also be considered in the procurement. For example the addition of headloss has the potential to reduce the useable volume of assets such as clearwells which have a large value to the City as an existing asset. The required support infrastructure for the UV will also be a significant consideration and the procurement has a clearly documented way to evaluate the costs which will be incurred by the City to ensure there is sufficient electrical supply for the new UV equipment.

The presentation will explain how the pre-procurement of the UV equipment and the installation of the UV reactors in the filter gallery will result in the lowest cost. It will also present the methodology used for evaluating life-cycle costs and the major costs to install the UV equipment as an example of how a procurement process and be planned to provide best overall value to a purchaser of a UV system.

Delivery of a Streamlined and Unconventional Dual-Vendor UV Design for a 100-Year Old Historic Drinking Water Treatment Plant
Gabe Maul, MWH Global

Abstract: Like most utilities, the City of West Palm Beach was challenged with strict budget and schedule constraints in the UV disinfection upgrades of their Water Treatment Plant (WTP). Project execution using design-build was not ideal because of the difficulty of retrofitting a 100-year old historic plant that was congested with pipework, some of which was undocumented. Instead of developing separate bid documents for UV equipment procurement, the project utilized an unconventional design approach that allowed the City to maintain competition between UV vendors.
Low pressure high output (LPHO) and medium pressure UV reactors were initially compared, and based on the projected lifecycle costs of LPHO versus MP systems, the City opted to allow bidding on LPHO systems only. Two LPHO UV systems were shortlisted; the preselection of these two systems was driven by lower operational costs in low UVT water. To further condense the design and procurement schedule, design disciplines worked overlapping schedules supported by development of a 3D model. The 3D design approach allowed information sharing between design disciplines to support clash detection. Additionally, design reviews with the client were substituted by workshops, allowing interactions between the owner and the design team, throughout the project.

This presentation will describe the budget and schedule challenges were addressed by designing mechanical, structural, architectural, electrical, and instrumentation and controls systems on common criteria such as footprint, UVT, headloss, pressure limits, installed power, type of cleaning system, power quality tolerances. The presentation will also provide audience members with an understanding of the extra requirements and risks that unconventional dual-vendor designs require, and how the design team can manage those risks to meet project budget and schedule constraints.

Designing a New UV Disinfection Facility for Multi-BARRIER Public Health Protection in Columbus, OH

Chris Schulz, CDM Smith

Abstract: The Division of Water (DOW) for Columbus, Ohio is currently expanding the Dublin Road Water Plant (DRWP) from a rated capacity of 65 to 80 mgd, and upgrading the existing conventional treatment and lime softening processes with the addition of ozone and biologically active carbon filters (BAF) for improved disinfection by-product control and anion exchange contactors for seasonal nitrate removal. Following completion of these ongoing construction projects, DOW plans to construct a new 94-mgd UV disinfection facility to provide a multi-barrier disinfection process (together with free chlorine) for microbial removal/inactivation.

The design of the UV disinfection facility involved a team effort among the DOW engineering section, DRWP plant staff and CDM Smith. Several key issues impacting the design of the UV system were discussed and decisions taken by this group through a series of focused, collaborative workshops during the preliminary design phase of the project. These included:

- Selection of a Cryptosporidium disinfection target and rationale for improving public health protection
- Impacts of the ozone-biofiltration process, currently under construction, on UV transmittance (UVT) and selection of a design value for UV disinfection
- Peak hour flow requirements for sizing the UV system based on future projected flows following the DRWP expansion
• UV system impacts on the plant hydraulic gradeline and design approaches to maximize downstream clearwell storage and CT credit for Giardia and virus inactivation
• UV equipment redundancy requirements for different design flows
• Evaluation of six site alternatives for locating the UV facility at DRWP
• Evaluation of medium pressure (MP) and low-pressure high-output (LPHO) UV systems based on industry track record, O&M requirements, head loss impacts and life-cycle costs.
• Development of a preliminary UV facility layout for the preferred site location—a retrofit structure inside an existing clearwell

This paper will present an overview of the DRWP UV project and the key design alternatives and technology issues addressed at the decision workshops during preliminary design, which supported the design of the new UV disinfection facility for DRWP.

**Welcome to the Modern Age: Upgrading Metro Vancouver's Seymour Capilano UV Disinfection Facility**

_Bryan Townsend and Ray Tarnai, Black & Veatch and Karen Tully, Metro Vancouver_

Abstract: Metro Vancouver’s Seymour-Capilano Filtration Plant (SCFP) has a treatment capacity of 1800 ML/day (475 US mgd), and consists of 24 filters with a single low pressure-high output UV reactor installed on each filter effluent train. The Wedeco K143 UV system, validated in 2005, was designed in accordance with the Tier 1 approach of the 2003 draft UV Disinfection Guidance Manual (UVDGM). UV systems validated with today’s modern techniques are far more efficient due to the minimization of validation uncertainty and bias as compared to similar systems validated in accordance with the protocols of the 2003 draft UVDGM. Black & Veatch conducted an evaluation of various K143 validations and identified the monitoring algorithm that was the most energy efficient and robust option in regards to its validation protocol, algorithm format, and associated validated limits. Statistical analyses demonstrated that although the two reactors differed in their validation piping and reactor arrangement, the algorithms developed from the more recent validation could be applied to the operation of the UV reactors at SCFP. Following regulatory approval, the updated UV reactor control philosophy and associated program were developed based on the new validation for implementation at SCFP.

Uploading and commissioning of the modified program was conducted in July 2016 followed by functional testing on selected reactors. The project is currently in its final stages with the modified programming expected to be uploaded to the remaining reactors in the near future following functional testing approval by Metro Vancouver. Once completed, the modified control strategy will not only greatly increase the UV system operating efficiency of the SCFP UV facility, but will also provide a modern, robust monitoring strategy with increased confidence that the required disinfection goals are maintained to protect public health.
NOTE: An introductory presentation on this project was given at the 2016 IUVA World Congress. This presentation will review some aspects previously discussed but will also cover details not yet presented, including required steps for regulatory approval, on-site testing activities and lessons learned.

**AOP AND REUSE 2**

**Permutations and Combinations for Designing the Largest Water Reuse Ultraviolet Disinfection System in North America**

*Bill Sotirakos and Doug Wing, Carollo Engineers, Inc.*

Abstract: The City of Santa Rosa (City) owns and operates the Laguna Treatment Plant (LTP) which has been providing California Title 22 reuse water since 1997. The LTP currently has a Trojan UV4000 installed and the City is in the process of replacing the existing medium-pressure ultraviolet (UV) system with a low-pressure, high-output (LPHO) UV system. The existing system has a site validated disinfection capacity of 48.5 mgd and the City is expanding the UV disinfection system capacity to 67 mgd to match the plant capacity. Prior work examined a broad range of alternative disinfection systems including pasteurization, sodium hypochlorite and ozonation. That work concluded that UV alone, or UV with side-stream hypochlorite were the best long-term solutions. This presentation will review the prior work as background, then lead into the extensive design effort. Redundancy has cost implications, our analysis documented how to maintain redundancy for 99% of the time while minimizing the overall cost. As part of the design effort the project team toured large UV systems with horizontal, vertical and inclined UV reactors across the United States to understand performance and equipment supplier service. Field notes will be shared as they had a large impact on preferred technology for the new UV system in Santa Rosa. This presentation will address the critical issue of flow split between the multiple UV channels and how computational fluid dynamics (CFD) was used as a design tool to help facilitate the design. The project also involves effluent diversion so that 100% of non-compliant flow is recirculated back to the head of the plant. This presentation will discuss the selection criteria used to select the preferred UV equipment manufacturer and will discuss the procurement process the City used to make this selection. Information gained during site visits of perspective UV manufacturers, and a review of channel cleaning methods, quartz sleeve cleaning methods, supplier services and support, and construction and life-cycle costs were all included in the review of and selection of the preferred supplier.

**Vacuum UV advanced oxidation of surface water and its impacts of biostability of the treated water**

*Madjid Mohseni, University of British Columbia*

Abstract: Vacuum UV (VUV) is a viable Advanced Oxidation Process (AOP) for the removal of micro-pollutants and various toxins in water. Despite its many
potentials, VUV along with other AOPs, face a potential challenge associated with their impact on biological stability of the treated water. This is because partial oxidation of natural organic matter in surface water during the treatment may lead to an increase in Assimilable Organic Carbon (AOC) and reduced biological stability.

This research aimed to examine and quantify the impact of VUV treatment on the biostability of the treated water. Surface water from various sources, with different TOC concentrations, underwent VUV radiation using two different experimental setups. First, kinetic studies were conducted using a customized completely mixed collimated beam unit allowing irradiation with 185 nm. A flow-through VUV reactor, equipped with a low-pressure ozone generating lamp emitting 254 nm and 185 nm UV, was used to evaluate the impact of different operating conditions. AOC concentration was quantitatively measured using Flow Cytometry bioassay. Also, biodegradable dissolved organic carbon (BDOC) and disinfection by-product formation potential (DBP-FP) of the treated water were monitored to further assess changes in biostability and water quality.

In this presentation, we highlight the results of our batch and flow-through experiments on changes in AOC and BDOC, as well as DBP-FPs, of the VUV treated water. The impacts of UV fluence and different salutes (inorganic ions) on biostability will also be discussed. These results are expected to be very beneficial for the scientific community in obtaining the most appropriate technologies.

**Enhancing Efficiency of UV Advanced Oxidation Processes via Iron Addition**  
*Sydney Ulliman, University of Colorado Boulder*

Abstract: "Addition of iron in the UV/H2O2 process has been shown to increase hydroxyl radical (HO·) production, and has been used to effectively reduce organics at circumneutral pH; however, previous studies have evaluated iron-assisted UV/H2O2 systems using impractically high iron (>0.3 mg/L) and hydrogen peroxide concentrations (>10 mg/L) in water treatment applications.

The goal of the present study was to evaluate the enhanced oxidation potential of iron-assisted UV/H2O2 using iron levels below USEPA secondary drinking water standards (0 to 0.3 mg/L). Chemically and kinetically diverse compounds para-chlorobenzoic acid (pCBA), carbamazepine (CBZ), and n-nitrosodimethylamine (NDMA) were selected to assess if low-levels of iron increased HO· radical production and observe chemical-specific responses to iron-enhanced UV/H2O2 treatment.

Iron-assisted UV/H2O2 efficiency at neutral pH was shown to be most influenced by photochemical and kinetic properties of the target chemical and the water matrix. For iron-assisted UV/H2O2 tests conducted in well water, a 20% increase in HO· production was observed as measured by the radical probe pCBA, and NDMA degradation rates increased by 14% to 24%. CBZ removal was neither improved or inhibited by the presence of iron. Interestingly, NDMA was the only chemical where
Iron addition increased removal rates in both low-carbon tap water (LCT) and well water. Furthermore, UV and iron, without H2O2 addition, was shown to enhance NDMA removal by 38% in LCT water and 8% in well water when compared to UV photolysis alone.

In summary, this work provides an understanding of the fundamental role of iron in a UV/H2O2 system.

Authors: Sydney Ulliman, Garrett McKay, Fernando Rosario-Ortiz, PhD, Karl G. Linden, PhD

The treatment of RO permeate for potable reuse using UV/chlorine advanced oxidation with low-pressure and medium-pressure UV lamps
Ron Hofmann, University of Toronto

Abstract: UV/chlorine advanced oxidation is of increasing interest for the treatment of wastewater for potable reuse where secondary wastewater effluent is typically treated by micro-filtration followed by reverse osmosis (RO) and UV advanced oxidation. 1,4-dioxane is a recalcitrant compound that can be present in the RO permeate along with other emerging contaminants. While UV/hydrogen peroxide has been used for oxidizing these contaminants, UV/chlorine has been shown to be an effective option, having lower energy requirements as well as advantages at the lower pH values typical of RO permeate. The objective of the study was to examine the treatment of 1,4-dioxane by UV/chlorine in simulated RO permeate using both low-pressure (LP) and medium-pressure (MP) UV lamps.

The study investigated the effect of pH, monochloramine, and nitrate on 1,4-dioxane degradation efficiency. Of these three parameters, pH had the most significant effect on the oxidation efficiency. 1,4-dioxane removal rates increased with a decrease in pH from 7.0 to 5.5. The highest removal rates (1-log to 1.5-log with the LP lamp and 1.4-log to 1.6-log with the MP lamp) were achieved at the lowest pH value (pH 5.5). This pH dependence was due to the increasing concentration of the OCl- ions as pH increases and its high reactivity with the hydroxyl radical ($k_{OH, OCl^-} = 8.8 \times 10^{9}$ M$^{-1}$s$^{-1}$). However this was partially mitigated with the MP lamp system because OCl- absorbs very powerfully at UV wavelengths from 260 to 340 nm where the MP lamp has significant output, thereby generating additional hydroxyl radicals even at very low OCl- concentrations. For exposure with both LP and MP lamps, monochloramine and nitrate concentrations had minimal effect on 1,4-dioxane degradation. This work shows that medium pressure UV/chlorine systems would have electrical energy efficiencies that are very competitive with low pressure systems at pH less than 6 and may be better than LP systems at pH above 6.5.

The experimental results were compared to a reaction kinetic model of the system, and showed good agreement. This helps to validate the model, which could then be used to interpolate or extrapolate (with caution) the results to other water quality conditions.
AOP AND REUSE 3

Uncensored: Incorporating UVI into EEO Based Control Systems for Potable Reuse
Austa Parker, Carollo Engineers

Abstract: Advanced purification technologies, including reverse osmosis (RO) and advanced oxidation processes (AOP), are proven technologies for chemical and pathogen removal in potable reuse applications. RO permeate has a high UV transmittance (UVT) and low total organic carbon (TOC) concentration, making it an ideal upstream technology for UV AOP. Currently, there are two UV AOP control system approaches to meet treatment goals for potable reuse: electrical energy per order (EEO) and UV dose. While both approaches are able to meet permit requirements and provide purified water protective of public health, neither of them provide a high degree of accuracy for true dose monitoring.

For potable reuse applications, UVT and UV intensity (UVI) are critical online tools to monitor disinfection dose at the UV AOP influent to ensure log-removal (LRV) permit requirements are being met. The currently installed and operational UV AOP systems for potable water reuse in California utilize the EEO concept. This approach (EEO control) does not take UVI into account for system control. After extensive startup testing, the City of Oxnard has developed a novel approach to UV AOP control, which is to integrate the real-time UVI data with the standard EEO approach. The UVI/Q approach is based upon the startup testing and the proven dose necessary to meet NDMA targets (<10 ppt) and the 0.5-log 1,4-dioxane reduction requirement.

This presentation will include data from the City of Oxnard as an example of a combined EEO and UVI control system for contaminant removal. Title 22 UV AOP permit implications of this new UV AOP control system will be presented, as well as a potable reuse UV AOP permitting update.

The How to Guide For UV Hypo – From Test to Design to Full Scale Operation
Jens Scheideler, Xylem Inc

Abstract: The combination of ultraviolet light and sodium hypochlorite has become a viable alternative to the classic UV AOP with hydrogen peroxide for potable reuse because of its economic benefits. This paper provides guidance how this new process is implemented starting from initial bench and pilot scale testing to the full scale design and operation. The data were gained from a 12 month pilot study and a corresponding bachelor thesis focusing on the fundamentals of this process as well as the operational data of the first full scale UV Hypo AOP system for potable reuse deployed at the Terminal Island Water Reclamation Facility in Los Angeles. Critical control points such as pH, scavenging potential, UV dose and free chlorine concentration are presented and how they were considered for the full scale design
and what the experiences are from full scale operations. The paper will also benchmark the UV hypo with the UV peroxide process with regards to economics and reliability.

**Managing UV/UVAOP System Conceptual Designs at Four City of Toronto WTPs – the Island WTP Case Study**

*Sarah Wilson, Liza Ballantyne - City of Toronto, Brandon Beck, Brian Sahely – AECOM*

Abstract: 4 Water Treatment Plants, 4 Consultants, 2.4 Billion litres of water per day, 1 objective: design an innovative UV system unique to each plant that achieves the City of Toronto’s disinfection and AOP goals.

In December 2015, the City of Toronto (City) completed a Water Quality Master Plan that recommended UV disinfection as the preferred additional Cryptosporidium reduction barrier at each of their 4 Water Treatment Plants. The City then retained 4 different Consultants, each working at a dedicated plant, to prepare a conceptual UV disinfection system design with the added ability to use UV Advanced Oxidation Process (UVAOP) for taste and odour and emerging contaminants.

This paper will explain the challenges that the City faced while managing 4 different Consultant teams and the approach that was developed to ensure each design satisfied the project objectives. It will also elaborate on the proposed design for one of the 4 Water Treatment Plants; the City’s 400 ML/d Island Water Treatment Plant. Not only is this facility located on an offshore island with limited installation options, but it also has contractual requirements that requires continuous 24/7 operation for 46 consecutive weeks of the year. This significantly impacted the UV disinfection location selection, constructability sequencing and several other factors.

The City's UV disinfection project takes an unorthodox spin on the traditional conceptual design/ detailed design-construction philosophy. It brings difficulties, it brings innovation, and it certainly brings a whole lot of excitement for everyone involved.

**Sulfamethazine degradation in water by the VUV/UV and VUV/UV/Chlorine process: Accurate determinations of kinetic parameters based on a mini-fluidic VUV/UV photoreaction system**

*Mengkai Li, Chinese Academy of Sciences*

Abstract: Conventional batch VUV/UV reactors have some problems in bench-scale studies, inducing a relatively low accuracy in the determination of VUV/UV photochemical kinetic parameters. A mini-fluidic VUV/UV photoreaction system (MVPS) was developed in our previous study, which can emit either combined VUV/UV (i.e., 185/254 nm) beams or sole UV beams into quartz tubes (containing the sample) with a nearly identical UV photon fluence. It was demonstrated as a powerful tool for studies on pollutant degradation by the VUV/UV process.

However, for the newly developed MVPS, the determination methods of
photochemical kinetic parameters (e.g., photon fluence-based rate constants and quantum yields) have not yet been well developed, and these will limit the MVPS application in photochemical studies.

In this study, we investigated the degradation of sulfamethazine (SMN), one of the most frequently detected antibiotics in the environment, by VUV/UV and VUV/UV/chlorine processes. The photon fluence rates of UV and VUV output by the MVPS were determined to be $8.88 \times 10^{-4}$ and $4.93 \times 10^{-5}$ einstein m$^{-2}$ s$^{-1}$, respectively, and the path-length of the UV beams in MVPS was determined to be 4.6 mm. Then, the determination methods of photochemical kinetic parameters (e.g., photon fluence-based rate constant and quantum yield) were developed based on the MVPS. The experimental results show that the VUV/UV/chlorine process exhibited a strong enhancement concerning the SMN degradation as compared to the total performance of the VUV/UV and UV/chlorine processes, although the photon fluence of the VUV only accounted for 5.6% of that of the UV and the initial chlorine concentration is only 0.5 mg/L. In addition, the second-order reaction rate constant between hydroxyl radical ($\bullet$OH) and SMN was determined to be $8.9 \times 10^{9}$ M$^{-1}$ s$^{-1}$ in VUV/UV irradiation experiments, which were conducted without addition of any other chemical. This study has developed methods for the determination of photochemical kinetic parameters using the newly developed MVPS and has demonstrated that the VUV/UV/chlorine process can be applied as a highly effective and energy-saving technology for the micro-pollutant remove in small-scale water treatment.

**DISINFECTION 4**

**Addressing variable UVT and peak flow challenges for existing wastewater UV disinfection with supplemental PAA**

*Michael Watts, Garver*

Abstract: Little Rock’s (AR) largest wastewater treatment facility (permitted discharge of up to 72 MGD) currently employs UV for effluent disinfection. However, meeting coliform discharge limits can be a challenge for the plant when flow exceeds 25 MGD (average day). In 2014, Garver applied in-channel biodosimetry testing to assess the range of doses that are feasible with Little Rock’s existing UV equipment. The data highlighted the specific water quality (effluent UV Transmittance, TSS) that can impair UV delivery. Alternative, supplemental disinfection strategies were evaluated to either replace or assist the existing UV system. A sequential chemical disinfectant upstream, followed by downstream ultraviolet irradiation, can be a useful tool for bridging the gap for under-performing or under-sized disinfection facilities. 15% Peracetic Acid (PAA) was investigated as a supplemental disinfectant to UV. The unique characteristics of PAA as an alternative chemical disinfectant: no residual quenching required, fast coliform inactivation kinetics and low residual contribution to effluent toxicity made PAA an ideal candidate to work in conjunction with low-UV doses. The results of an
on-going, 12-month, full-scale trial of sequential PAA and UV disinfection at the LRW facility will also be presented to highlight the enhanced treatment capacity of LRW's disinfection facilities. The benefits of PAA/UV disinfection will be discussed including minimizing UV system cleaning and maintenance, and optimization of both PAA and UV dosing, which could have significant implications for wastewater utilities considering adopting new disinfection strategies or design of new disinfection facilities.

UV sensor to monitor the low wavelength contribution to the dose of MP UV disinfection systems
Sven Kaemmerer, Xylem Services GmbH

Abstract: Since Wedeco demonstrated the low wavelength issue through the validation of their Quadron 3000 system in 2011, several approaches have been discussed to address the various associated challenges. One often discussed approach is to monitor the low wavelength part (below 240nm) of medium pressure radiation spectrum. Following this path, Wedeco developed a low wavelength sensor as a supplementary UV sensor to the established germicidal sensor. In order to fit the UV sensor to existing systems and being compliant to the relevant UV sensor norms, Wedeco based their sensor on the established ONORM design. The developed sensor is characterized by a dynamic range of at least 5 magnitudes and is based on a completely different diode and filter material. During the development of the sensor it became obvious that the currently widely used SiC diode material is not sufficient for such a sensor. Two filter designs were tested to achieve the best fit to the corresponding dose of a MP UV system in clear separation from the germicidal range. In this presentation we will give insights into the details of the sensor concept, with a focus on the selectivity for the wavelength range above and below 240 nm to acquire a distinct signal that is meaningful in conjunction with the common germicidal sensor. Furthermore, the behavior of critical key parameters such as long-term stability, accuracy and spectral response will be discussed.

A simpler and more accurate method for collimated beam experiments
James Bolton, Bolton Photosciences Inc.

Abstract: The current IUVA Protocol for Collimated Beam experiments is complex and involves many factors, each of which contributes to the total uncertainty. Also there is evidence that there may be some edge effects from UV reflected from the sidewalls of the Petri dish. Finally, there is no convenient way to continuously record the incident irradiance.
This paper will describe a simpler and more accurate CB method based on the photon flux concepts.
The new method involves a conventional CB setup but with a ring mask placed over the Petri dish. The purpose of the ring mask is to assure that no UV beams reach the walls of the Petri dish. The method also involves a tiny micro fluorescent silica
detector (MFSD) to allow a continuous recording of the photon flux passing through the hole in the ring mask.

The KI/KIO3 actinometer is used to determine the photon flux entering the water and to calibrate the MFSD.

The advantages of the new method are that:

1. There is no need to determine the PF, RF and DF factors eliminating error contributions from those factors.
2. Any problems from reflection of UV off the inner walls of the Petri dish are eliminated.
3. The average irradiance can be determined continuously and thus takes account of any fluctuations in the UV lamp output.
4. It is very accurate, since the principal source of absolute error is the value of the quantum yield, for which the absolute error is less than 3%.

INNOVATIONS AND APPLICATIONS 1

To the moon and beyond: UV lights the way out of Low Earth Orbit

Rich Simons, AquiSense Technologies

Abstract: Since November 2nd 2000 there has been a permanent human presence in space. However, this position is tenuous: with the need for constant resupply missions to the ISS, it remains tied to the earth at a distance of ~250 miles. For successful, long-term, lunar missions we will need a new set of tools.

A core principle of future space stations is self-sufficiency, with the eventual goal of a closed-loop ecosystem. This engineered environment is designed for the complete regeneration of all resources.

Closed-loop ecosystems require the recirculation of resources, which can cause a build-up of biological contaminants. The ISS is often thought of as a sterile lab, something akin to a clean room, but that’s far from the case. Despite best efforts, reports have shown the growth of mould in living quarters and contamination of potable water sources. Biological contamination can never truly be eliminated within a habitable environment. “Life, finds a way”. Control of bio-contamination within life support systems is an operational imperative: it is a matter of life or death for astronauts who depend on them.

Over decades UV has been proven as a broadband decontamination method for air and water systems. Can UV revolutionise the life support systems of manned space exploration?

In January 2016 AquiSense Technologies Europe joined the trans-European BIOWYSE consortium to help develop a system for the safe storage, and rapid monitoring, decontamination, and delivery of drinking water for future space
exploration missions. This paper outlines the critical role of ultraviolet disinfection in both the BIOWYSE project, and the future space exploration.

Co-authors: Oliver Lawal, Jennifer Pagan

High-Power UV for Ballast Water Treatment: Possible but not Practical
Po-Shun Chan, Trojan Technologies

Abstract: The recent USCG decision to reject the MPN method for measuring treatment of 10-50 um organisms in type-approval testing, eliminates a method for proper measurement of UV treatment which inactivates organisms by damaging their DNA, preventing reproduction and thus preventing infections and invasions. MPN is based on culturing, so it is able to properly measure the impacts of UV treatment.

The approved measurement method for 10-50 um organisms in USCG type-approval testing is the ETV Stain method, which measures certain cellular features (esterase activity, membrane integrity) that do not respond to UV damage that otherwise destroys reproductive capabilities. With massive (e.g. 10x) overdoses of UV irradiation, some organisms can be severely damaged and made to show impacts via the stain method (though some organisms will show no response with stains at all). This paper will use UV dose-response data and UV reactor models to explain how such UV systems will have proportionately larger size, cost of equipment, and power requirements. It will also explain how UV dose delivery depends upon water clarity and flow rate, leading to another strategy of designing a UV system with a lesser increase (e.g. 5x), but that can only be used in clear waters and/or at lower flow rates. While conventional UV technology provides adequate environmental protection, these high-power approaches using massive UV systems to show impacts via stains results in UV systems that are either too large to be economically practical, or too limited in operational water quality range to be practical to shipowners.

The MPN Method and UV-Based Treatment Systems
Brian Petri, Trojan Technologies

Abstract: The United States Coast Guard (USCG) recently rejected an application for the use of the MPN Dilution-Culture Method (MPN) as an alternative method for measuring treatment of organisms in the 10-50 um size category, leaving the use of fluorescein-based stains (FDA and CMFDA) as the only approved method. The stains are purported to assess the live/dead status of organisms, and are thus thought to be “safer” than a culture-based method like MPN that assesses reproductive ability. However, the stains do not measure damage done by UV treatment systems. UV systems inactivate organisms by damaging their DNA and preventing reproduction and thus preventing invasions. The stains measure the activity of an organism’s esterase system and its membrane integrity, which are not directly impacted by UV treatment. Significantly higher UV doses and significantly larger UV systems will be required to meet USCG standards using stains as the
measurement method. This paper will give an overview of the issue and will also review the scientific work done to address it, both for the Stain Method and the MPN Method, in the area of ballast water treatment.

**The Development of an Alternative Method to Quantify the Number of Living 10-50 um Organisms for Ballast Water Management System Type-Approval Tests**

*Brian Petri, Trojan Technologies*

Abstract: A two-part method was developed to measure the number of living 10-50 um organisms for ballast water management system (BWMS) type-approval tests. The first part is a chlorophyll-based most probable number (MPN) dilution-culture technique for reproductive autotrophs. The second part is an epi-fluorescent microscopic examination method for motile heterotrophs. Epi-fluorescence is used to identify and eliminate chlorophyll-containing autotrophs from the count. In this method, living organisms are defined as autotrophs capable of reproduction and heterotrophs that exhibit motility. Elimination of reproductive capacity renders autotrophs harmless (invasions are prevented) and elimination of motility is a good indication of heterotroph death. This two-part method is applicable to all treatment technologies. For UV-based BWMSs that work by eliminating reproductive capacity, autotrophs will be accurately measured while heterotrophs will not (heterotrophs rendered non-reproductive can still be motile). Thus the heterotroph method is conservative for evaluating UV-based BWMSs. This method combined existing methods employed at three BWMS test facilities. QAQC protocols were developed to measure the accuracy and precision of the methods using standard organisms (Tetraselmis and Brachionus). For the autotroph method, development experiments were done to determine standard media and temperature for incubations, the required fluorescence scoring criteria, and the required monitoring period and frequency. The accuracy of the autotroph method on field samples was determined by measuring the rate of false negatives (organisms not demonstrating growth) via microscopic methods applied to pre-incubation and post-incubation samples.

**INNOVATIONS AND APPLICATIONS 2**

**Effect of UV treatment on formation of disinfection by-products in chlorinated seawater swimming pools**

*Waqas Cheema, Technical University of Denmark*

Abstract: A laboratory scale study has been conducted to analyse the effect of UV irradiation on the formation of several DBPs in seawater pools. The pool samples were collected from three indoor public seawater pools and exposed to two different UV doses and then chlorinated in dark for 24 h.
In this study, effect on the formation of various volatile disinfection by-products e.g. trihalomethanes (THM), haloacetonitriles (HAN) and haloacetic acids (HAA), were observed in laboratory experiments using medium pressure UV treatment after post-UV chlorination. Results showed that post-UV chlorine demand was increased, dose dependently, with UV treatment. Results also indicated that post-UV chlorination induced formation of several DBPs. However, the formation of HAAs were decreased significantly, dose dependently, with post-UV chlorination which could also mean that HAAs decomposition might occur due to heat from UV exposure. Furthermore, the breakage of HAAs molecules into smaller molecules would also mean that they resulted an increase in THMs. Overall, the formation of HAAs were decreased but the formation of THMs and HANs were increased with post-UV chlorination. There is need to standardize the application of UV system in the seawater pool.

New Water Brew - Recycling Water for the Highest Purpose
Abigail Antolovich, Xylem

Abstract: As demand for sustainable water supplies increases, attention has turned to potable water reuse. Although the concept may still seem extraneous to the general public, water purveyors are already pilot testing and implementing full scale treatment around the world. This barrier of public perception is largely due to a lack of information presented to the public about how far today's water treatment technologies have advanced. To address this, creative and engaging approaches to demonstrating potable water reuse can help to capture public attention and deliver the message about the safety and effectiveness of potable water reuse. Efforts to promote the benefits of potable reuse, and increase demand, should not just be for municipal use, but also for commercial use. Therefore, the WateReuse Association formed a team to produce potable recycled water for distribution to home brewers associations throughout the US for the purposes of demonstrating the effectiveness of advanced treatment technologies for potable reuse and increase public acceptance and awareness of potable reuse. A pilot scale system was operated at Hillsborough County Utilities tertiary reclaimed water facility in Tampa, FL, incorporating ultrafiltration, reverse osmosis, and advanced oxidation with ultraviolet light and peroxide. Results from the pilot study demonstrated that this treatment process produced high quality water drinking water. This project is the first direct potable reuse project in the state of Florida and provides an outstanding example of validating advanced technology for this application while developing an outreach and education approach to garner public acceptance.

Bacteria Inactivation via X-ray-induced UVC Radioluminescence: Toward In-situ Biofouling Prevention in Membrane Modules
Ezra Cates, Clemson University

Abstract: We have begun development of an experimental technology – radioluminescence membrane biofouling control (RMBC) – which employs luminescent particles excited by externally supplied X-rays to generate germicidal
UVC within otherwise inaccessible confines. To investigate its potential as a transformative new approach for biofouling control in seawater reverse osmosis, radioluminescent (RL) materials were synthesized and evaluated for bactericidal performance. Assessment of three Pr3+-activated phosphor candidates revealed LaPO4:Pr3+ to have the most favorable luminescence properties; over 2-log inactivation of E. coli was achieved when a layer of bacterial suspension over a thin phosphor coating received a 74 Gy X-ray dose at 150 kVp. The effect of UVC RL resulted in a doubling of inactivation rates over X-ray irradiation alone. Further efforts including X-ray penetration modeling and RO membrane UVC dose tolerance suggested that UVC RL is a promising new method for biofouling control in spiral-wound membrane elements. Economic and practical considerations for application to seawater reverse osmosis will also be presented.
INNOVATIONS AND APPLICATIONS 3

Experimental Evaluation of UV Reactors in Series

Yuri Lawryshyn, University of Toronto

Abstract: A recent paper by Lawryshyn and Hofmann (2015) utilized theory to show that two UV reactors placed in series would provide at least twice the reduction equivalent dose (RED) of a single reactor for a given target organism, provided that the single reactor validated RED was determined using a test organism whose sensitivity was at least twice that of the target organism. It was shown that these conditions held true even under the worst-case mixing conditions between the two reactors. The objective of this study is to experimentally demonstrate the validity of the theory. A flow loop is used together with multiple low pressure NSF 55 certified UV reactors in series, using MS2 and Bacillus pumilus as challenge organisms. Bacillus pumilus is twice as resistant to UV as MS2 (D10 of 50-55 mJ/cm2 for Bacillus pumilus compared to 20-25 mJ/cm2 for MS2), thus providing the required conditions for demonstration of the theory. Experiments are conducted over a range of flow rates, UVT, and intermixing scenarios. Furthermore, while it is impossible to experimentally reproduce the worst-case mixing conditions between the two reactors, it is possible to approach such conditions by appropriately blocking lamp output within a single reactor. Thus, some of the experimental results approach the worst-case scenario. Computational fluid dynamics (CFD) modelling is used to compliment the experimental results. At present, the study is about half complete, with final results expected by November.

It is hoped that this work will provide additional assurance to regulators about conditions that would allow multiple UV reactors to be used in series to achieve high levels of disinfection. An obvious immediate benefit would be the use of multiple NSF 55 systems for adenovirus control for small systems. The work also provides information that can be used in the optimization of the design of new UV systems that include multiple banks of UV.

Method for the determination of the UVC efficiency of a UV lamp mounted inside a UV reactor

James Bolton, Bolton Photosciences Inc.

Abstract: IUVA has established a Protocol for measuring the UVC efficiency of low-pressure UV lamps mounted in air. However, to date, no one has published a method for determining the UVC efficiency for UV lamps mounted inside a UV reactor. A micro fluorescent silica detector (MFSD), which is is only 1.0 mm long and 0.3 mm diameter, was mounted on a low-pressure high output (amalgam) UV lamp. First the UV lamp was mounted in air and its UVC efficiency was measured in a two-chamber test facility. At the same time, the MFSD reading and the lamp surface temperature were recorded.
Then the UV lamp, with the MFSD attached, was mounted in an annular UV reactor. DI water was circulated from a tank with a chiller and heater. The UV lamp was turned on and allowed to come to a steady state. MFSD readings and lamp surface temperatures were recorded every 5 °C up to 40 °C. The assumption made here is that the relative change in the MFSD reading between the air setup and the UV reactor setup reveals the relative change in the UV output from the UV lamp. Hence, multiplication of the UVC efficiency in air by the ratio of the MFSD readings in the UV reactor to the MFSD reading in air yield the UVC efficiency of the UV lamp in the UV reactor. The presentation will show plots of the UVC output, voltage and UVC efficiency of the tested lamps over the 7 – 40 °C temperature range.

**A COMPARISON OF UV TRANSMITTANCE SENSORS AT WWWTP’s - Success and Challenges**  
*Gary Hunter, Black & Veatch*

Abstract: Transmittance is one of the key control parameters used by UV system to adjust the applied dose. Validation equations and thus control of the UV system can be controlled using an on-line sensor. So if the on-line UV sensor is measuring higher than the actual transmittance value then the system is wasting energy and if the system is measuring lower than the actual transmittance value then potential for compliance may occur. Two comparison studies have been conducted to evaluate various operational parameters of each sensor. During the first study, the wastewater plant had already selected for the testing had installed a HACH UVAS sensor as part of a UV installation. Two additional On-line UV transmittance sensors were selected based on availability and ease of installation. Data was collected for 30 days at 5 minute intervals from the three sensors and compared to spot check grab sampling data collected by City staff. Results of from all three sensors did find variability between the on-line measurements and data collected from the City’s laboratory. During the second study, UV sensors (the HACH UVAS and Sensorx LED units) were located at a nutrient removal treatment plant with filtration. Data was collected for 90 days at 5 minute intervals. The results of this study indicated very close correlation of UV transmittance measurements between the two sensors. A summary of operational considerations developed from both studies are presented. In addition a present worth analysis using the results from both studies was completed to evaluate each of the sensors evaluated during the studies.

**Decomposition of Sucralose in a Small Scale 172nm Reactor**  
*Jennifer Pagan, Aquisense Technologies*

Abstract: Jennifer Pagan(1), Steven Pugh(1), Olya Keen(2)
1.Aquisense Technologies  
2.The University of North Carolina at Charlotte Dept. of Civil Engineering

Sucralose has been recommended as a good indicator compound for quantifying decomposition of organics in wastewater. A key benefit of sucralose as an indicator
compound is its lack of absorbance at wavelengths longer than 220nm. A significant amount of research has been performed on sucralse and other organic contaminants in water using Advanced Oxidation Processes (AOP) where H2O2 is photolyzed by low or medium pressure ultraviolet (UV) lamps to generate hydroxyl radicals which effectively oxidize the sucralse. The rate at which the sucralse degrades during AOP reactions was found to be slower than that of other organic compounds which reinforced its usefulness as an indicator compound for organics in wastewater. This application of sucralse as an indicator is only valid if its decomposition is solely via hydroxyl radicals. New models would need to be developed if other mechanisms of decomposition such as direct photolysis were introduced in the system.

Vacuum Ultraviolet (VUV) sources are improving and will likely become more prevalent in commercial water treatment systems in the future. In a VUV system with a short pathlength, sucralse will undergo direct photolysis as well as dissociation via hydroxyl radicals. Less research has been performed with sucralse and VUV sources. This study attempts to quantify the ratio of direct photolysis and oxidation induced decomposition of sucralse in a small scale reactor with a 172nm plasma source. The effect of pH on the reactions is also explored and samples are examined using Shimadzu TOC-LCPN organic carbon analyzer.

**LEDs 2**

**UV Flux Measurement of Light Emitting Diodes for Water Treatment**

*Gordon Knight, Trojan Technologies*

Abstract: Ultraviolet light emitting diodes (LEDs) offer an instant-on light source in the germicidal region of the electromagnetic spectrum for water treatment systems. Total UV flux values for commercial devices now range from ~10 – 50 mW per device for LEDs emitting in the 265 – 290 nm spectral region. The advent of array devices presents a challenge for measuring the total UV flux, since the total active area of the array can exceed the entrance area of integrating spheres normally used for UV flux measurement. A compact goniospectroradiometer (GSR) is used to measure the irradiance of LED devices as a function of angle, and then integrated over the entire hemisphere of emission for the LED to yield the total UV flux of the device. The total flux determined by the GSR is then compared to the flux measured by an integrating sphere for devices that can be measured with a sphere. Using the devices of five UV LED manufacturers, the average difference between the two measurement methods is 10 ± 10%, which is within the total uncertainties of the two methods. The measured UV flux values are then compared to the manufacturer’s specifications at the same drive current of the device. The average difference between specified and determined UV flux values is only 2±9%, except for one outlying device with 30% higher UV flux than the specified value. This indicates that the stated UV flux values of the manufacturers are in agreement or are conservative when compared to measured values. The germicidal UV flux is then calculated from measured UV flux values. A LED device with a rated peak emission
wavelength of 285 nm actually had a measured emission wavelength of 290 nm, with a 61% derating of the determined UV flux when the germicidal UV flux was calculated.

**Computational modeling of UV-LED reactors**  
*Fariborz Taghipour, University of British Columbia (UBC)*

Abstract: UV-LEDs offer several advantages compared to traditional UV lamps, perhaps the most significant being flexibility in the reactor design of water purification systems. Given their small size UV-LEDs offer a higher degree of freedom in reactor design and optimization. The performance of UV reactor systems is a function of the interaction of three phenomena: hydrodynamics, optics, and kinetics. We will discuss the differences between the simulation of these phenomena in UV lamp and UV-LED reactors.

We will present a precise method for modeling microorganism inactivation irradiated by UV-LEs taking into account the characteristics of the radiation source and the optical properties of the medium. In this approach, the exact emission spectrum of UV-LED is taken into consideration by treating it as a polychromatic UV source. Further, we will describe a UV-LED radiation model that takes into account refraction, reflection, and absorption of the medium to compute the fluence rate distribution. Finally, an integrated model of simulating the behavior of UV-LED reactors will be presented.

**Validating a Testing Protocol for Measurement of UV-LED Lamp Output**  
*Kari Sholtes, University of Colorado Boulder*

Abstract: The development of a protocol was initiated in 2015 to enable agreement on deep Ultraviolet Light Emitting Diode (UV-C LED) output testing conditions, methods, and reporting which will enable greater transparency to system designers, regulators, researchers, and end users. This protocol is an IUVA initiative, undertaken by a working group of the IUVA Manufacturers Council, and is designed to not only facilitate standardized laboratory methods but also create and validate a formal protocol which laboratories can use to better describe the output of their UV-LEDs. The protocol was designed to test and compare standardized UV-C LED lamp emission spectra (power output and wavelength) with standardized equipment under different ambient conditions with different operators.

An independent third party at the University of Colorado Boulder developed and validated the proposed testing protocol for the measurement of UV-LED lamp output. The standardized protocol and calibrated equipment was sent to fourteen domestic and international participants (UV LED manufacturers, system designers, and researchers) for round robin testing in 2016. Measurements consisted of experimental conditions, output spectrum, and radiometer readings. While environmental conditions varied slightly between participants, variability in output spectrum and radiometer readings resulted largely from operational differences,
likely distance from and orientation of the source to the sensor. All participant results have been anonymized and compiled into a report of outcomes, and the protocol with results will be circulated for review and published by IUVA. The final protocol, findings of the Round Robin data and summary of the project outcomes will be presented.

MUNICIPAL TREATMENT 2

From Liability to Reliability: The LADWP Groundwater Experience
James Collins, Arcadis

Abstract: The City of Los Angeles encompasses an area of 465 square miles with a population of nearly 4 million residents and an annual average water consumption of approximately 215 billion gallons. Local groundwater provides approximately 11% of the City’s total water supply and the City has a goal of achieving 50% of the water sources supply from the San Fernando Basin by 2035. Groundwater supplies provide an important local renewable water supply to supplement surface water supplies, especially given recent drought conditions.

Unfortunately, over 70% of the Los Angeles Department of Water and Power (LADWP) groundwater production wells in the San Fernando Basin (SFB) are impacted by contamination caused by various commercial and industrial activities. The SFB is an aquifer that provides drinking water to over 800,000 residents within the City of Los Angeles. Contamination has been caused by improper storage, handling, and disposal of hazardous chemicals by industries, as well as commercial and heavy industrial activities dating back to the 1940s.

Without comprehensive containment and groundwater basin remediation, the City will significantly lose the ability to use this valuable local resource within the next decade. To improve groundwater clean-up and increase the supply of high quality renewable water resources for the City, LADWP is undertaking a program to evaluate and implement groundwater treatment throughout the SFB. This 10 year program of up to $600M will greatly improve local renewable water supplies for the City.

Treatment alternatives are currently being evaluated for the first well field and illustrates the complexity of trying to implement treatment of the various contamination plumes given the extensive pumping activity within the basin. Challenges have included evaluation of contaminants of concern, treatment alternatives, and facility sizing given project uncertainties. Extensive modeling and bench-scale testing have been completed to evaluate potential treatment alternatives. UV advanced oxidation is one technology that is being evaluated as an option to treat the primary contaminant of concern (i.e., 1,4-dioxane) as well as other contaminants of concern (i.e., volatile organic compounds).
This paper will present the approach used by LADWP for beginning the expansion of their groundwater treatment facilities and will provide the following information:

- Overview of LADWP San Fernando Basin Program
- Challenges faced during the development of the treatment approach
- Approaches used to evaluate treatment alternatives and fast track the design and construction phases to expedite treatment
- Details of the site specific bench-scale testing of the UV advanced oxidation to evaluate treatment efficiency for the target contaminants of concern.

Evaluation of UV and Ozone Mediated Advanced Oxidation for Santa Monica’s New Olympic Treatment Plant

Bryan Townsend, Black & Veatch

Abstract: The City of Santa Monica collaborated with Black & Veatch to pilot test various treatment technologies that will be implemented at a new 3.5 mgd water treatment facility. When constructed, the Olympic Treatment Plant (OTP) will treat groundwater from existing and future wells to supplement and enhance the reliability of the city’s water supply. Key organic constituents of concern in the groundwater include 1, 4-Dioxane and a variety of volatile organic compounds (VOCs): trichloroethylene, tetrachloroethylene, methyl tert-butyl ether, 1, 1-Dichloroethene, and cis 1, 2-Dichloroethene. Various treatment solutions were investigated to determine the best available technologies selected for pilot testing, which began September 2015.

Piloted technologies consisted of greensand filtration, reverse osmosis, air stripping, and advanced oxidation. Advanced oxidation processes (AOP) included pilot testing of ultraviolet light/chlorine (UV/Cl2) AOP and ozone/hydrogen peroxide (O3/H2O2) AOP. Ultraviolet light/hydrogen peroxide (UV/H2O2) AOP was evaluated on the bench scale using a collimated beam device. UV/Cl2 AOP was not viable for 1,4-Dioxane or VOC treatment, likely due to a pH of 6.5, which represents the upper limit for application of this technology. While O3/H2O2 was demonstrated to achieve the target 1,4-Dioxane removal, the high concentration of bromide in the source water resulted in significant bromate formation. It was concluded that UV/H2O2 AOP is the best available technology, as testing results consistently demonstrated that it could reliably meet the target 1,4-Dioxane removal with no byproduct formation concerns.

Test results were used to develop conceptual-level design criteria, performance models, cost estimates and preliminary site layouts for the future full scale OTP. This presentation will focus on the AOP technologies evaluated in this project, including the pilot testing, technology comparisons, and development of the UV/H2O2 conceptual design for the full scale OTP.
Replacing membranes with UV at the Appleton Water Treatment Facility

Todd Elliott, CH2M

Abstract: The city of Appleton faced operational challenges with their ultrafiltration system and sought alternative, lower cost pathogen barriers to achieve treatment objectives. UV disinfection coupled with water softening and GAC contactor conversion to GAC filters was selected as the preferred treatment approach. This presentation will highlight the key drivers for the project, the major design elements, construction and start up challenges and opportunities, with a focus on the UV disinfection portion of the project.