

# IUVA NEWS

ISSN 1528-2017  
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## FEATURES

**UV Disinfection of Storm Water Overflows and Low UVT Wastewaters**

**Medium Pressure UV Treatment of Ballast Water**

**Drinking Water UV Operation Without On-Line UVT Monitoring: The Default UVT and Sensor Setpoint Approaches to Validation**



**18 - 21  
September  
2011**

**2nd North American Conference on  
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Highlight of the 2nd North American Conference

### Editor in Chief:

#### Jim Bolton, Ph.D.

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Paul Swaim

# A MESSAGE

from the IUVA President

## Paul Swaim

As I write this, I am wrapping up preparations and getting ready to head to the IUVA/IOA 2nd North American Conference on Ozone, Ultraviolet, and Advanced Oxidation Technologies in Toronto, Canada. While I always enjoy spending time in beautiful Toronto (and currently hold the Canadian national record for the all-time slowest slap-shot ever recorded by an adult, with a 17 mile per hour effort at the Hockey Hall of Fame), I am most excited to see old friends, meet new friends, and share in the technology transfer among the leading people in the UV field. We have a great program planned, with well over 200 delegates, dozens of great presentations, a Sunday UV workshop, and a Wednesday UV technical tour. By the time you read this, the conference will have come to a close – we hope it was a great experience for you.

The IUVA has had a terrific year, with a very successful World Congress in Paris, France and our Toronto event. We've instituted some structural changes to position our organization to be able to do more, with our new Executive Director and Regional Hub Directors. It's exciting to work with these folks every day, with lots of energy and ideas and so much that the IUVA can do. In the July IUVA News, I said that there will be a lot of activity in the coming months. As you look through this issue of IUVA News, you'll see notices of some great upcoming events across the globe, including the October 20 Workshop on Drinking Water Disinfection with Ultraviolet Light in Tracy, CA, the November 22 Workshop on Ballast Water Treatment in Hamburg, Germany, and the December 7 Workshop in London, UK, "UV for Water Treatment: Recent Implementation and Trends." I hope that you are making plans to attend one or more of these events.

For those of you who can't travel to one of these events, look for announcements of upcoming webcasts on key UV topics as well. Our team is hard at work planning additional future events so we can continue to share information with each other on UV technology and what it can do for public health and the environment.

Along those lines, earlier this week, I was invited to present on the topic of sustainable water treatment to a local meeting of the Society of American Military Engineers. Listening most avidly to my presentation were several students in the audience. We all work with UV regularly, and perhaps from time to time, we forget what a truly exciting technology it is. There are lots of eager students out there, and the IUVA can do more to spread the word on what UV

can do and how it does it. One of the many activities scheduled for Toronto is a kickoff meeting for a new IUVA Strategic Initiative on Educational Opportunities. I invite you to contact us if you're interested in assisting as part of this team, and helping us get the word out on UV to the next generation.

- Paul



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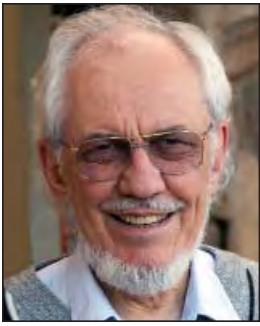
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Jim Bolton

# EDITORIAL

**Jim Bolton**  
*Editor-in-Chief*

This issue has three interesting articles illustrating application of UV to storm water treatment, ballast water treatment and operation and monitoring of UV reactors without UV sensors.

I am always interested in articles that will be of broad interest to the UV community. I am particularly interested in Application Notes from UV companies. So if you have an unusual application, let me know and I'll help you to develop an Application Note.

Finally, feedback is always good, so if you have some changes you would like to see in IUVA News or have comments (positive or negative) about something published, write me a "Letter to the Editor".

This will be my second last issue, since I am retiring (again) as Editor-in-Chief of IUVA News at the end of December. Deb Martinez will be the new Editor-in-Chief in 2012.

- Jim



Deb Martinez

# MESSAGE

**Deb Martinez**  
*IUVA Executive Director*

As executive director of the International Ultraviolet Association, I am focused on fulfilling the association's mission and goals. Though I have only been with organization for a short time, I am focused on the strategic positioning of IUVA as the thought leader in the ultraviolet field. I find the work very rewarding, and I have done things that are unprecedented in IUVA's history.

Since June 2011, I have initiated new strategic plans, revamped the look of IUVA's website and reconditioned financials. Because of my marketing tactics new members have been enrolling on a weekly basis.

The website is being completely rebuilt to better display news of interest to our members as well as to be easier to update and maintain for IUVA staff. New features will include direct online purchasing of memberships and Buyer's Guide listings, a conference registration and management system, and a new look and feel better suited to modern web browsers. The website will also reside on faster, more stable servers for better performance and security.

IUVA has several exciting events to look forward to in the near future. With several workshops upcoming, from "Drinking Water Disinfection with Ultraviolet Light" on October 20, in Tracy, CA to "UV for Water Treatment: Recent Implementation and Trends on December 7, in London, England, we are positioning ourselves to provide education and professional development of our members. I look forward to continuing IUVA's already well-established success.

- Deb



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# REPORT FROM IUVA



*Bertrand Dussert*

## **Bertrand Dussert:** **Director of the IUVA Americas Hub Office**

Dear IUVA colleagues,

On June 1st, 2011, promptly following our very successful World Congress in Paris, the IUVA opened its Americas hub office. I have the distinct honor of serving as its director.

The major objectives of this hub are four-fold: 1) Increase the relevancy of the IUVA as the leading authority for UV technologies in our core municipal water/wastewater markets, 2) Expand into new applications/markets, 3) Expand into new territories, and 4) Educate/outreach/promote. Accomplishing these objectives will lead to membership growth and increased financial stability for the Association.

Since it opened, the Americas hub office has been busy with events in North America. We represented the IUVA at the American Water Works Association's Annual Conference & Exposition (Washington, DC, June 12-16). While this year's attendance was lower than in previous years, our presence increased our credibility as a key trade association in the water industry.

I also had the pleasure to attend the APIC 2011 Annual Conference in Baltimore, MD (June 27-29). APIC stands for Association for Professionals in Infection Control and Epidemiology. I was relatively surprised to see numerous suppliers of UV equipment exhibiting their products for disinfection of hospital rooms. This clearly represents a growth market in which the IUVA must gain greater relevance.

Working closely with our executive director and the leadership of the IOA Pan American Group (PAG) in planning the event, our 2nd North American Conference on Ozone and Ultraviolet Technologies (Toronto, Canada, September 18-21) promises to be very successful. Shortly thereafter (October 20), we will conduct a workshop on drinking water disinfection in Cary, CA, which includes a tour of the Tesla UV disinfection facility (third largest drinking water installation in North America).

In the upcoming months, we will be carrying out a series of webcasts to address 'hot' issues in the municipal water/wastewater industry. We also plan to address the industrial water market by organizing a workshop on the use of UV technologies for the fast-growing ballast water treatment market. We are also discussing the potential for a workshop in Chile, a country with increased interest for UV technologies. Please stay tuned for the details of each activity.

I will also work closely with our executive director as we explore cooperation opportunities with environmental and water associations.

I look forward to working with the leadership team and each one of you. I would very much appreciate your feedback on how the Americas hub office can best serve you. Please do not hesitate to contact me at [Americas@iuva.org](mailto:Americas@iuva.org).

- *Bertrand*

## **Andreas Kolch:** Director of the IUVA **European and Middle East (EMEA) Hub**

As reported in the last IUVA News, the EMEA Hub is up and running since June 2011. We have started to communicate to our EMEA membership base and the responses are quite encouraging – so thanks to everyone who got back to us. At present, we have developed a series of events for the region starting at the end of this year with a time line until early 2013.

The first event will be in Hamburg, Germany on 22 November and will be solely focused on ballast water treatment. This event will be conducted in cooperation with the German BSH and ttz and the registration will be complimentary. The 2<sup>nd</sup> event will be held at the Congress Centre in London on 7 December in cooperation with Wrc and will follow up on the regulatory situation for UV systems in the UK with speakers from UK utilities and regulators as well as international experts. More information can be found at the registration websites under [www.iuva.org](http://www.iuva.org).

Want us to come to your country? Please don't hesitate to contact us under [EMEA@iuva.org](mailto:EMEA@iuva.org). We are keen to hear about your ideas and how we can support you.

- *Andreas*

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# IUVA AWARDS

## 2nd North American Conference on Ozone, Ultraviolet and Advanced Oxidation Technologies, Toronto

### Best Ozone- and UV-related student presentations

**Winner: Devendra Borikar of the University of British Columbia & Sarah Bounty (right) of the University of Colorado at Boulder**

Students played an active role in the 2nd North American Conference on Ozone, Ultraviolet and Advanced Oxidation Technologies, held in Toronto in September. A team of enthusiastic students volunteered to monitor rooms, record continuing education credits, and coordinate many other aspects of the busy conference schedule. These students did a superb job and were an integral part of the conference's success.

Students also had a strong presence in the technical sessions, with 11 student presentations on subjects ranging from the ability of ozone to treat industrial waste streams, to the fate of oil dispersants used in the Gulf oil spill. Both the IOA and



*Sarah Bounty*

the IUVA presented awards to the best ozone- and UV-related student presentations. Devendra Borikar of the University of British Columbia won the award for the best ozone-related paper, focusing on the removal of emerging contaminants using ozone and ozone-related advanced oxidation processes. Sarah Bounty (left) of the University of Colorado at Boulder won the IUVA's award for her work

on the inactivation of adenovirus by UV/hydrogen peroxide treatment. Her supervisor is Prof. Karl Linden (left).

The IOA and the IUVA congratulate Devendra and Sarah for their excellent work, and hope that students will continue to be actively engaged at future conferences and Association events.

# UV INDUSTRY NEWS

The following are interesting items of note from IUVA Member Announcements

### Trojan UV System Offers Disinfection of CSO, Stormwater Flows

[www.waterworld.com/index/display/article-display/6349355685/articles/waterworld/volume-27/issue-9/weftec-preview/uv-system-offers-disinfection-of-cso-stormwater-flows.html](http://www.waterworld.com/index/display/article-display/6349355685/articles/waterworld/volume-27/issue-9/weftec-preview/uv-system-offers-disinfection-of-cso-stormwater-flows.html)

Chlorine has traditionally been used to provide disinfection of Combined Sewer Overflows due to its low cost. However, the growing awareness of the adverse environmental impacts associated with the byproducts of chlorination has led to increasingly restrictive chlorine residual requirements. A proven alternative disinfectant is the application of Ultraviolet (UV) disinfection for stormwater overflows.

UV disinfection technology has been used successfully in low UV transmittance (UVT) applications through proper UV

reactor design and validation. The TrojanUV4000Plus™ system from Trojan Technologies has been tested, installed and is operating in a number of low UVT applications. The system has several design features that enable effective disinfection for challenging waters...

[www.trojanuv.com](http://www.trojanuv.com)

### 2011 AHE Conference Showcases Ultraviolet Devices V-360° Room Sanitizer

[www.webwire.com/ViewPressRel.asp?ald=146534](http://www.webwire.com/ViewPressRel.asp?ald=146534)

...An exciting new technology for the battle against healthcare-associated infections (HAIs) will be displayed at this year's conference by UltraViolet Devices, Inc. (UVDI) in booth #905. UVDI will showcase the V-360° Room Sanitizer which is designed to provide a measured dose of ultraviolet



germicidal irradiation (UVGI) for rapid and effective surface disinfection in healthcare environments. The V-360° emits 360 degrees of UV-C energy and can achieve 99% disinfection of target surfaces in minutes.

“Hospital environmental service professionals know that preventing surface transmitted nosocomial infection is a serious challenge,” reported Richard Hayes, President of UltraViolet Devices, Inc. “New technology, such as UVDI’s V-360° Room Sanitizer, provides EVS staff a powerful new weapon for inactivating infectious agents including MRSA and *C. difficile*.”...

[www.uvdi.com](http://www.uvdi.com)

## **Isala Hospital in Zwolle, the Netherlands, is trialing Berson's medium pressure UV systems for the first time, for treating hospital wastewater prior to discharge.**

[www.plantengineer.org.uk/article/36945/Berson-ultraviolet-treats-hospital-wastewater.aspx](http://www.plantengineer.org.uk/article/36945/Berson-ultraviolet-treats-hospital-wastewater.aspx)

Peter Menne, Berson's European sales manager, explains that UV is applied in combination with hydrogen peroxide to generate OH radicals in a so-called advanced oxidation process (AOP).

OH radicals attack the pharmaceutical residues and -ray contrast compounds, breaking them down into H<sub>2</sub>O, CO<sub>2</sub> and harmless metabolites, he explains...

[www.bersonuv.com/frontend/scripts/index.php?groupId=100&setMainAreaTemplatePath=mainarea\\_productlist.html](http://www.bersonuv.com/frontend/scripts/index.php?groupId=100&setMainAreaTemplatePath=mainarea_productlist.html)

## **UV technology for TOC reduction in Power plants and Semi-conductor industries**

[www.environmental-expert.com/news/uv-technology-for-toc-reduction-in-power-plants-and-semi-conductor-industries-255083](http://www.environmental-expert.com/news/uv-technology-for-toc-reduction-in-power-plants-and-semi-conductor-industries-255083)

ESCO International has recently designed and supplied TOC UV reduction systems for a power plant in Russia successfully treating process water to reduce TOC levels from 700 ppb to below 100 ppb.

Our scope of supply included three UV systems to be installed after a Reverse Osmosis (RO) system and, before a membrane degasifier, EDI and polishing mixed bed, with process water flow rate of 25 m<sup>3</sup>/h for each TOC UV system. The reduction target of less than 100 ppb was successfully met thanks to ESCO’s compact design

[www.escouk.com](http://www.escouk.com)

## **New Long-Life, Heraeus UV Modules Provide Cold Disinfection for Food Packaging**

[www.packagingeurope.com/Packaging-Europe-News/42928/New-LongLife-Heraeus-UV-Modules-Provide-Cold-Disinfection-for-Food-Packaging.html](http://www.packagingeurope.com/Packaging-Europe-News/42928/New-LongLife-Heraeus-UV-Modules-Provide-Cold-Disinfection-for-Food-Packaging.html)

The new Premium UV module from Heraeus Noblelight has been specially developed to provide cold UV disinfection for food packaging. It offers a compact design, allowing easy retrofit within existing production lines, and features a lamp life of around 12,000 hours, three times that of competitive lamps. Its geometry fits it especially for in-line filling machines with four to twelve rows of cups...

[http://heraeus-noblelight.com/en/home/noblelight\\_home.aspx](http://heraeus-noblelight.com/en/home/noblelight_home.aspx)

## **UVDI Nominated for Prestigious Award by the San Fernando Valley Business Journal**

[www.webwire.com/ViewPressRel.asp?ald=146106](http://www.webwire.com/ViewPressRel.asp?ald=146106)

Recently, UltraViolet Devices, Inc. (UVDI) was notified by the *San Fernando Valley Business Journal* that the company has been nominated as part of the publication’s 2011 Family Business Awards. UVDI is one of 56 local California companies nominated this year by the journal...

[www.uvdi.com](http://www.uvdi.com)

## **Vinci to build sewer systems in five Dominican Republic cities**

<http://home.nestor.minsk.by/build/news/2011/09/1906.html>

Vinci, through its subsidiary Vinci Construction Grands Projets, has signed a design-build contract with INAPA (Instituto Nacional de Aguas Potables y Alcantarillados) covering wastewater collection, transfer and treatment systems in the cities of Monte Cristi, Neiba, Azua, San Jose de Ocoa and San Cristobal in the Dominican Republic. This project is part of the Dominican government's cholera eradication programme...

...These facilities comply with sustainable development criteria: simple operation, environmental protection and high-quality treatment. For example, final disinfection will take place in an ultraviolet radiation facility; its power will be supplied by photovoltaic panels, which cover 80% of overall energy requirements.

[www.vinci.com/vinci.nsf/en/index.htm](http://www.vinci.com/vinci.nsf/en/index.htm)



# NEW IUVA MEMBERS

Welcome to the Following  
**NEW IUVA Members:**

## Americas

- Sarah Bounty** – (Student)
- John Burban**
- Cody Charnas**
- Stephen Frayne**
- Neil Graf**
- Jerry Jia**
- William Kerfoot**
- Richard Martin**
- Robin McLean**
- Gerson Neiva**
- Austa Parker** – (Student)
- Rajul Randive**
- Nidhi Rawat**
- Michael Sarchese**
- Karen Tully**
- Patrick Young** – (Student)
- Zurui Yu**

## Europe/Middle East/Africa

- George Wang**
- Amir Hamidi** – (Student)
- Barrie Holden**

## Asia/Australasia

- Annie An**
- Andrew Lee**
- Chii Shang**
- Shinji Kameda**

**IN ADDITION, WE ARE PLEASED TO WELCOME  
A NEW CORPORATE MEMBER:**

**Bronze Scientific International Ltd.,  
United Kingdom**

## UPCOMING CONFERENCES

**15 – 19 October 2011**  
**WEFTEC-2011** - Los Angeles, CA

**10 – 14 June 2012**  
**ACE-12** - Dallas, TX

**20 October 2011**  
**Drinking Water Disinfection with  
Ultraviolet Light - Workshop**  
Tracy, CA

**16 – 21 September 2012**  
**IWA World Congress and Exhibition,**  
Busan, South Korea

**13 – 17 November 2011**  
**Water Quality Technology Conference  
and Exposition**  
Phoenix, AZ

**29 September -  
3 October 2012**  
**WEFTEC-2012** – New Orleans, LA

**22 November 2011**  
**UV-Ballast Water Workshop -  
more information coming**  
Hamburg, Germany

**9 – 13 June 2013**  
**ACE-13** - Denver, CO

**24 – 27 September 2013**  
**7th UV and 21st Ozone Congresses**  
Las Vegas Mirage Resort, Las Vegas, NV

**7 December 2011**  
**UV for Water Treatment: Recent  
Implementation and Trends**  
London, England

**Look Here for Future  
Announcements**

## 2ND NORTH AMERICAN CONFERENCE ON OZONE, ULTRAVIOLET & ADVANCED OXIDATION TECHNOLOGIES

**18-21 September 2011 - Toronto, Canada**

This was the second joint conference organized by the International Ozone Association (IOA) and IUVA and was a great success (as was the first one in Boston in 2009). There were 299 delegates and 32 companies in the Exhibition.

The conference opened by Saad Jasim, President of the International Ozone Association, Pan-American Group and Paul Swaim, President of IUVA. This was followed with keynote talks by Pierre Trepanier, Commissioner, international Joint Commission and Lee Anne Jones, President of the Ontario Water Works Association.

There were about 85 talks covering a wide range of topics. The UV session focused on UV Validation and Monitoring, Advanced Oxidation applications and studies, UV design, UV case studies and research, and UV treatment research.

The Conference Program and Proceedings can be obtained from Deb Martinez ([deb.martinez@iuav.org](mailto:deb.martinez@iuav.org)).

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## Ultraviolet (UV) Disinfection Equipment: Major Applications and Global Markets

[www.reportlinker.com/p0619276/Ultraviolet-\(UV\)-Disinfection-Equipment-Major-Applications-and-Global-Markets.html](http://www.reportlinker.com/p0619276/Ultraviolet-(UV)-Disinfection-Equipment-Major-Applications-and-Global-Markets.html)

**NEW YORK, Sept. 22, 2011 /PRNewswire/** -- Reportlinker.com announces that a new market research report is available in its catalogue:

### REPORT HIGHLIGHTS

- The global market for ultraviolet (UV) light disinfection equipment is estimated to be worth \$885 million in 2011, and is expected to grow at a compound annual growth rate (CAGR) of 12.7% during the next 5 years. At this rate, the overall market worth will reach \$1.6 billion in 2016.
- The market for water treatment equipment is the largest and one of the fastest growing. Valued at approximately \$536 million in 2011, this market is expected to rise at a CAGR of 11.4% and reach \$921 million by 2016.
- Wastewater treatment is the fastest growing global market for UV disinfection equipment. Market size is estimated to be worth \$198 million in 2011 and growing at a CAGR of 18.2%. It is expected to reach \$456 million by 2016.

## Metro Vancouver UV plant is built to be sustainable

[www.journalofcommerce.com/article/id46678](http://www.journalofcommerce.com/article/id46678)

When Metro Vancouver's new \$110 million Coquitlam UV plant is completed in 2014, it will be more than just another utility building in the bush.

The structure, which is targeting minimum LEED Silver, will combine all the green lessons learned at the LEED Gold Seymour Capilano filtration facility.

It will also feature a new ultraviolet (UV) system by Trojan Technologies...

## CDC notes 72% rise in water-related outbreaks

[www.cidrap.umn.edu/cidrap/content/fs/food-disease/news/sep2311waterborne.html](http://www.cidrap.umn.edu/cidrap/content/fs/food-disease/news/sep2311waterborne.html)

**Sep 23, 2011 (CIDRAP News)** -- Outbreaks linked to both recreational water and drinking water have increased substantially, according to two reports from the US Centers for Disease Control and Prevention (CDC), which said that

*Cryptosporidium* contamination and groundwater problems pose special challenges.

The reports contain 2007 and 2008 data from waterborne illness surveillance collected by the CDC, the Environmental Protection Agency (EPA), and the Council of State and Territorial Epidemiologists (CSTE). The reports, one on recreational water and one focusing mainly on drinking water, were published today as *Morbidity and Mortality Weekly Report (MMWR)* surveillance summaries...

### Snapshot of recreational water outbreaks

In 2007 and 2008, 134 outbreaks linked to recreational water were reported, up from 78 in the previous 2-year period—a nearly 72% increase. The CDC said in the first report that this is the most outbreaks ever reported during a 2-year period...

### Drinking Water Outbreak Patterns

Outbreaks involving drinking water rose 80% over the previous 2 years, according to the second CDC report, which put the total at 36 outbreaks from 23 states and Puerto Rico. Those outbreaks caused 4,128 illnesses and 3 deaths. More than half (21) were linked to bacterial contamination, and 13 were associated with groundwater...

## CH2M HILL's Luggage Point Advanced Water Treatment Plant Project Wins The 2011 WateReuse International Award

[www.wateronline.com/article.mvc/CH2M-HILLS-Luggage-Point-Advanced-Water-0001](http://www.wateronline.com/article.mvc/CH2M-HILLS-Luggage-Point-Advanced-Water-0001)

CH2M HILL is pleased to announce that the firm has been awarded the 2011 WateReuse International Award from the WateReuse Association for the Luggage Point Advanced Water Treatment Plant Project (AWTP). CH2M HILL accepted the award on Sept. 12 during the 26<sup>TH</sup> Annual WateReuse Symposium held in Phoenix, Arizona...

...The 18.5-million gallons/day plant uses a multi-barrier treatment train that includes chemical precipitation, microfiltration, reverse osmosis, and ultraviolet disinfection/advanced oxidation...

# UV DISINFECTION OF STORM WATER OVERFLOWS AND LOW UVT WASTEWATERS

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## ABSTRACT

UV is commonly used for disinfecting many types of waters including treated wastewater, reclaimed wastewater for reuse, and drinking water. UV technology is also now being applied to low quality waters, such as primary treated wastewater and combined sewer overflows (CSO). Relative to traditional UV applications, disinfection of low quality water presents unique design challenges because of the higher concentration of solids and the darker water (high absorbance of UV). Through proper design and validation, UV has been proven effective and is installed at full-scale facilities. New research and carbon footprint analyses also illustrate that UV is a more sustainable approach to disinfection and has a smaller carbon footprint than either chemical disinfection or construction of storm water storage facilities.

**Keywords:** Ultraviolet, UV, disinfection, storm water, combined sewer overflow, CSO, low quality wastewater

## INTRODUCTION

Ultraviolet (UV) is used for disinfecting many types of waters including low quality waters, such as primary treated wastewater and combined sewer overflows (CSO). Combined sewer systems are sewers that are designed to collect rainwater runoff and domestic wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the municipal wastewater treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows, called combined sewer overflows (CSOs), contain not only storm water but also raw sanitary wastewater. CSOs may be thought of as a type of urban wet weather discharge. Since the untreated (or partially treated) effluent flows directly into the river or water bodies, the receiving body can be microbiologically disturbed for months before the river and marine ecosystems recover. For this reason, treatment of CSOs is becoming a regulatory requirement in many regions in order to protect receiving water bodies and the ecology within those areas.

Chlorine has traditionally been used to provide disinfection of CSOs due to its low cost. However, the growing awareness of the adverse environmental impacts associated with the byproducts of chlorination has led to increasingly restrictive chlorine residual requirements. A proven alternative disinfectant is the application of UV disinfection for storm-water overflows. UV has an advantage compared to chemical disinfectants because there are no health and safety concerns related to chemical storage and handling, it does not lead to environmentally harmful disinfection by-products (DBPs), and UV does not require the additional complexity and cost of subsequent chemical removal or treatment technologies (e.g., dechlorination, re-aeration) to ensure environmentally safe discharges. Although UV energy demands are typically higher than conventional UV applications, as a result of the lower UV transmittance of the water, the chlorine demands for chemical disinfection are also greater because of the higher levels of background organics. In many cases disinfection targets for these low water quality applications are not as stringent, so the design UV doses and overall energy consumption are not excessive. UV is a cost-effective technology for disinfecting low quality wastewaters, as long as the technical challenges imposed by them are met through proper design and testing of UV reactors for these applications.

Disinfection of storm water significantly reduces the release of pathogens into receiving waters. Indicator species are used to test for the presence of harmful pathogens in storm water discharges. Although these species are not normally harmful to humans, their presence in surface waters can indicate contamination from the fecal matter of warm-blooded animals, a source of pathogens. Various indicator species have been used to assess water quality degradation due to pathogens, including total coliform, fecal coliform, *Escherichia coli* (*E. coli*) and enterococci. In many parts of the United States, enterococci is commonly used in marine waters as an indicator in shellfish (a route of ingestion of pathogens to humans) harvesting waters and recreational waters.

The high flow rate and volume of storm water, combined with the inherently high suspended solids concentration, variable temperature, and disinfectant-resistant pathogens requires a disinfection technology with rapid oxidation and powerful pathogen-killing capabilities.

Traditional disinfectants, such as chlorine, have rapid oxidation capabilities and are relatively low cost, making

*Continued on pg 14*

Continued from pg 13

them suitable and effective for storm waters. However, due to the high flow rates, volumes and chlorine demand of storm waters, effective treatment can require a lengthy contact time resulting in large equipment footprint and construction costs. In addition, the high chlorine doses applied can potentially result in a high chlorine residual and toxic DBPs in receiving waters.

Like all disinfection technologies, UV disinfection technology design is a function of the water quality being treated. As a physical (vs. chemical) treatment, the relationships between UV disinfection and water quality are more easily defined and quantitated. It is therefore possible, once the relevant water quality parameters are defined for a storm-water event, to properly design the UV reactor to meet the pathogen disinfection requirements for future storm-water events.

## THE PROPER DESIGN OF UV REACTORS FOR LOW WATER QUALITY WASTEWATERS

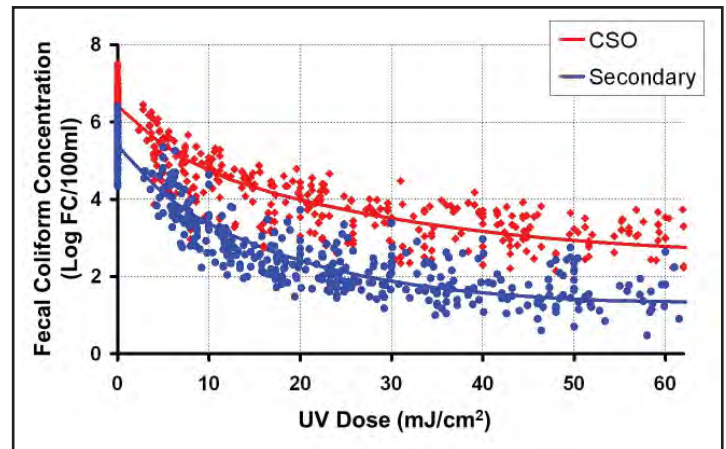
The objective for UV disinfection is to transfer UV energy into the water. Low quality wastewaters have low UV transmittance (UVT) (high absorbance), thus the UV reactor design challenge is a greater one, because a higher percentage of the UV is absorbed in a shorter distance – compared to secondary or tertiary wastewater.

The key to proper UV reactor design is to optimize the effective water layer between the UV lamps for the transmittance of the water in consideration. In low transmittance water, the effective water layers need to be smaller, which can be accomplished with more powerful lamps, a narrower spacing, or with hydraulic devices to induce streamlines and direct flow towards the lamps. Each of these options must be evaluated against its trade-offs. For instance, higher power lamps can have higher overall energy consumption at the cost of wider lamp spacing leading to a lower head loss reactor design. Alternately, with lower powered lamps, the required narrow lamp spacing and hydraulic devices can increase head loss. Higher head loss can result in water level increases in an open-channel UV reactor, which can lead to a large water layer above the top of lamps (short-circuiting), or leave a large section of downstream lamps exposed to air. These zones with large water layers or exposed lamps have little to no disinfection, and reactors with these hydraulic flaws will fail when challenged in full-scale operation.

Any fraction of the flow that receives less than optimal UV doses, whether due to short-circuiting or through exposed lamps, will limit the ultimate performance of the reactor. Trojan Technologies has overcome these constraints and limitations by using highly-sophisticated computational fluid dynamics (CFD) modeling coupled with accurate irradiance models to design UV reactors for storm-water applications. Using industry-standard bioassay protocols to test and validate reactor performance, UV reactors have been shown to be effective for these challenging low water quality

applications.

Low quality wastewaters typically have high levels of suspended solids, and these particles can harbor microorganisms that are resistant to disinfectants. UV dose – response curves are generated in a laboratory using calibrated collimated-beam devices to quantify the relationship between applied UV dose and microorganism survival. Because of the large variability of water quality properties, extensive collimated beam UV dose – response



**Figure 1:** Collimated beam UV dose-response curves for fecal coliforms comparing low quality (CSO) and high quality (secondary) wastewaters. These data show between-process differences, within-process variability, and the impact of difficult-to-disinfect solids.

tests are required to properly characterize different waters. The UV dose – response curves for microorganisms in low quality wastewaters typically have two slopes, characterizing the easy-to-disinfect ‘free-floating’ microorganisms, and the more challenging particle-associated microorganisms (see **Figure 1**). Typical disinfection objectives for low-quality wastewater range from one to three log reductions of the target or indicator organism. In response, the design UV doses to meet these requirements do not need to be excessively high because the limits are typically reached by disinfecting the free-floating microorganisms.

In typical applications requiring the disinfection of stormwaters, the CSO or primary wastewaters are characterized by high flows, low UV transmittance and high total suspended solids. UV disinfection technology testing is typically carried out at lower flow rates because of logistical limitations, and scale-up becomes a necessary task. In testing, the UVT is manually lowered using industry-accepted UVT modifiers. Water quality and suspended solids are determined by frequent collimated-beam sampling and testing. Over the years, UV dose response data has been collected that spans a wide range of water qualities and sources, as well as thousands of locations around the globe. This database contains UV dose response data for multiple types of upstream treatment processes including: conventional activated sludge, fixed film processes, membranes, media filtration, stormwaters, primary/chemically enhanced primary



treatment and combined sewer overflow (CSO). Storm waters have high suspended solids, and the effectiveness of any UV design dose depends on the disinfectability of the water and in turn on the properties of the suspended solids in the wastewater. The relationships between total suspended solids (TSS) and UVT can be derived from this database and used for sizing.

As an example, from Trojan's database, the typical water quality during a stormwater event can be:

- 200 mg/L TSS (peak value, first flush), 90 mg/L TSS (extended storm value)
- UVT varies during the storm between <20% during first flush to >65% near end of storm when water is mostly rainwater.

This representative data, combined with water quality from sampling events, provides the Owner and Design Engineer with a high level of confidence that the UV system design will consistently meet the discharge requirements set out for the application in a cost-effective manner.

## UV EQUIPMENT DESIGN AND KEY CONSIDERATIONS FOR OPERATION IN LOW UVT WATER

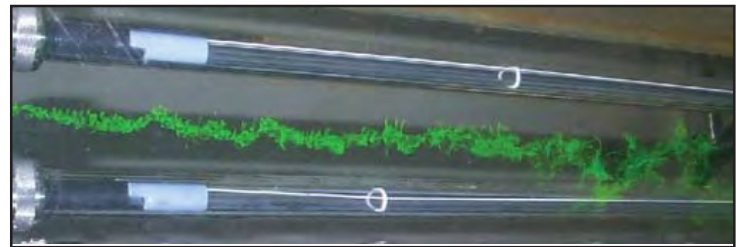
UV disinfection technology has been used successfully in low UVT applications through proper UV reactor design and validation. The TrojanUV4000Plus™ reactor has been tested, installed and is operating in a number of low UVT applications and has several design features that enable cost-effective disinfection for challenging waters.

**UV Energy Source:** Effluent flows by gravity through a fully submerged, tubular reactor, where it is exposed to high levels of UV generated by medium pressure (MP) high intensity lamps. The innovative, contoured reactor walls ensure stringent control of the water layer around the lamps for consistent disinfection regardless of flow rate or water level. UV modules house the lamps, quartz sleeves and cleaning system and pivot into the reactor opening at upstream and downstream ends. Lamps are placed in a staggered array, spaced evenly apart and optimized to balance the tradeoffs between head loss generated and mixing induced. After extensive CFD modeling and field testing, vortex mixers (shown in **Figure 2**) were successfully incorporated into the module design to optimize performance at lower UVTs. The vortex mixers are mounted on the quartz sleeves, and increase flow turbulence and mixing around the lamps (**Figures 3 and 4**).

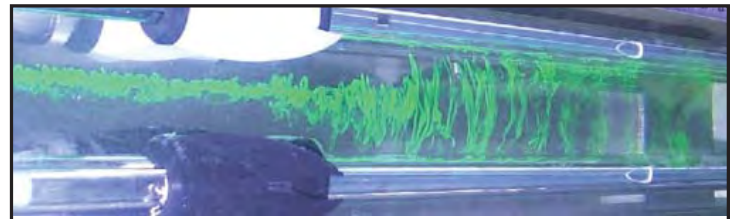
**Monitoring:** An important consideration in the operation of a low UVT system is the ability to respond to varying water quality conditions. Over the course of a storm, the water quality can vary significantly, and the UV system must respond accordingly to ensure full treatment performance and to optimize power and lamp use. Key monitoring



**Figure 2.** Vortex mixers mounted on quartz sleeves housing medium pressure UV lamps provide additional mixing and direct the low UVT water toward the high intensity light source.



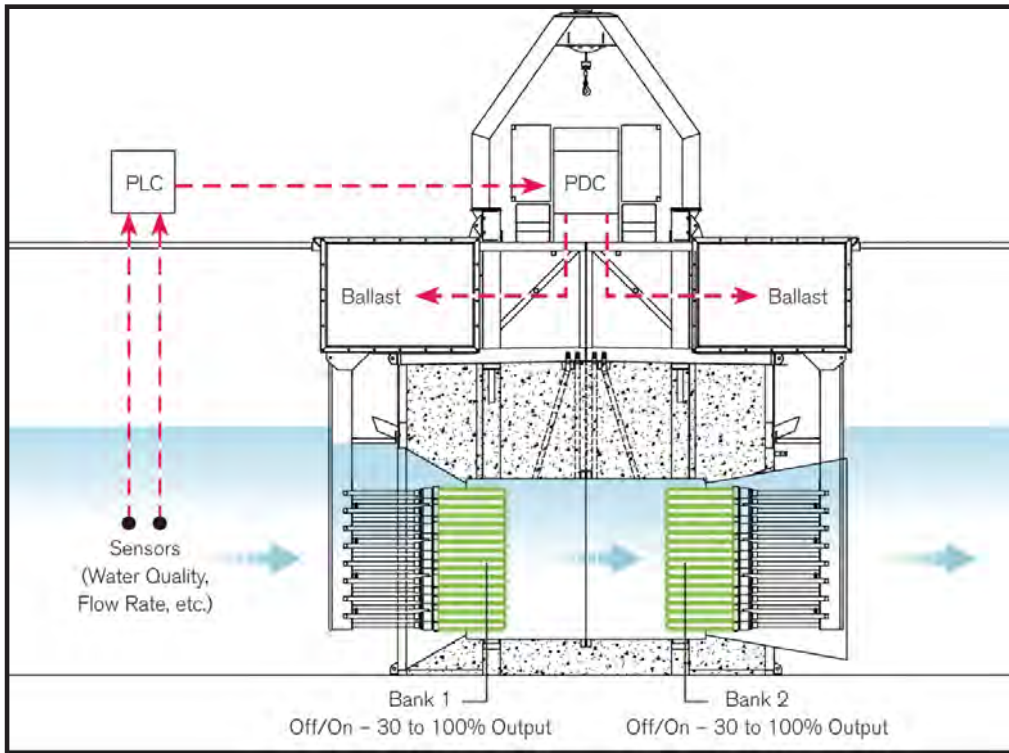
**Figure 3.** Dye tests illustrate potential paths of short-circuiting where water does not reach the UV lamps, resulting in poor performance and potential reactor failure.



**Figure 4.** With vortex mixers, additional turbulence is induced, ensuring that particles and microorganisms reach the UV lamps for reliable disinfection.

equipment includes UV intensity sensors to measure lamp output, flow meters and on-line UVT monitoring to track water quality throughout the storm event. As operating conditions and water quality fluctuate, the UV system controller (PLC) automatically and continuously calculates operational power settings required to achieve the UV lamp output necessary to ensure adequate disinfection. The Power Distribution Center (PDC) houses the high-efficiency, variable output ballasts which deliver the power to the lamps. A typical schematic of a UV4000 System used for storm water treatment is shown in **Figure 5**.

*Continued on pg 16*



**Figure 5.** Typical Schematic of UV4000 System for Storm Water Treatment

**Maintenance:** Another design challenge equally critical to ensure proper performance and long-term operation is to consider the quartz sleeve fouling rates and extent, as well as the solution for foulant removal. If not fully addressed, there is a performance risk (UV is unable to reach the water) and a maintenance risk (Operators will spend excessive time cleaning the UV system).

Because the low UVT, higher solids and in some cases, the type of coagulants used, the rate and degree of fouling on the quartz sleeves can be accelerated in low UVT applications. Fouling must be removed from the quartz sleeves to maximize the UV transfer to the water. Options for fouling removal include manual cleaning, semi-automatic or automatic cleaning mechanisms.

Regardless of type, it is critical that both mechanical (wipe-action) and chemical (dissolve-action) are provided to fully remove organic and inorganic fouling. Selected commercially-available UV systems today offer automatic systems that provide both mechanical and chemical cleaning methods to completely remove fouling, optimize UV delivery and reduce operator maintenance.

## INDEPENDENT BIOASSAY VALIDATION

In April 2010, bioassay validation testing was performed on the TrojanUV4000Plus™ disinfection system equipped with vortex mixers. The bioassay testing was conducted by

adding non-pathogenic indicator viruses, (MS2 and T1UV bacteriophages) to the influent water. A UVT modifier (Superhume™) was used to adjust the UVT of the water to desired low levels, thereby representing low UVT wastewaters and CSO applications. Samples were collected from the influent and effluent of the UV reactor to determine reactor disinfection efficiency over a range of flows, UVTs, and lamp power settings. Analyses were performed on the data generated to determine reduction equivalent doses (RED) as a function of flow, water quality (UVT), lamp power setting, and microbe sensitivity. All sampling and data analyses were witnessed by an independent third party to validate the results

The completed validation report presents the validation data for the range of UVT tested (10 to 70%). The delivered UV dose is shown along with the relationship to flow rate for the range of water quality tested. The completed validation

report and data contained therein can then be utilized to verify system sizing for low UVT wastewaters, thus providing confidence that disinfection levels will be achieved.

## FULL-SCALE APPLICATIONS OF UV FOR STORMWATER TREATMENT

It is estimated that over one billion gallons per day (44 million m<sup>3</sup>/s) of storm water and/or very low quality wastewater (low UVT) is currently being treated with UV disinfection with installations in North America, Europe, Australia and Asia. Prior to selecting UV technology, several of these municipalities underwent a comprehensive bench scale and/or full scale field testing project to confirm UV's effectiveness on their challenging effluent.

One particular municipality who evaluated, tested and installed UV for their CSO treatment is the Cog Moors Wastewater Treatment Works (WwTW) facility located near Cardiff, UK in the Barry catchment (southwestern UK region). The region in South Wales served by the Cog Moors WwTW includes three popular bathing water beaches. To protect public health, the Environment Agency Wales introduced stringent consents and storm-water spill limits of only three per bathing season, posing a compliance challenge for the Cog Moors WwTW. The plant is equipped with an activated sludge process for secondary treatment and utilizes storm



tanks to capture and store the storm flows. The facility evaluated several options that would enable compliance with the Bathing Water Directives (including the limit on spill events per season). Options included: (1) provision of additional 25,000 m<sup>3</sup> storm-water storage capacity and (2) UV disinfection of 2,380 L/s (54 MGD) storm flow with UVT down to 30%. Three key evaluations led to the selection of UV disinfection technology. First, a cost analysis, for CAPEX and OPEX provision of additional storm storage capacity was 2.3 times more costly than installation and intermittent operation of UV disinfection based on a 20-year Net Present Value comparison (Imtech Process, Ltd). Secondly, the carbon footprint was evaluated for both options. It was concluded that UV treatment generated approximately one tenth the amount of greenhouse gas emissions. The largest contributing factor for the storm-water storage option was the embodied emissions of greenhouse gas due to the use of concrete for construction of the storm-water tanks.

In comparison, UV had a smaller footprint, used a fraction of the concrete and power consumption was intermittent (during storm events only) making the UV option even more attractive in the sustainability evaluation. Lastly, a pilot study was conducted to confirm the effectiveness of UV disinfection for the Cog Moors CSO effluent – being the first UV plant in the UK designed to treat storm-water flows. Since commissioning in 2009, the UV plant has operated successfully. Effluent quality monitoring has shown the plant meets the

required bacteriological reductions, ensuring that local beaches were safe for the community.

## SUMMARY

To ensure reliable disinfection performance in low UVT applications, it is critical that the equipment manufacturer has knowledge and understanding in the following:

- Water quality or comparable water quality (i.e. from a historical database) whether it be primary effluent or CSOs
- Proper UV reactor design including the science of UV disinfection as it relates to overcoming the challenges of delivering UV energy to the pathogens of concern.
- Successful history of UV installations for storm-water disinfection

The equipment selected should be from a reputable manufacturer with good scientific understanding and a demonstrated history of applying UV for low quality wastewaters. The design trade-offs, in terms of head loss and power consumption, are a function of UV lamp intensity, lamp spacing and mixing and must be evaluated. Finally, the selected UV-reactor configuration must have been verified through field-testing and independent bioassay validation to guarantee performance at a full-scale level.

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# MEDIUM PRESSURE UV TREATMENT OF BALLAST WATER

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## ABSTRACT

This study was undertaken to evaluate the ultraviolet (UV) inactivation efficacy for several indigenous species and the formation of other oxidants and by-products by the treatment of ballast water with medium pressure UV (MPUV). The ballast water treatment system used in this study was composed of filtration modules as a pre-treatment process, followed by a UV process equipped with a polychromatic MPUV lamp. The experiments were performed in seawater and brackish water with a flow rate of 250 m<sup>3</sup>/h. The disinfection efficacy of this system successfully met the D-2 regulation of the International Marine Organization (IMO). In addition, oxidants [i.e., H<sub>2</sub>O<sub>2</sub>, total residual oxidants (TRO) and OH radicals] and potential halogenated by-products (i.e., HAAs and THMs), which might be formed after the MPUV treatment, were investigated.

In conclusion, the ballast water treatment system employing the MPUV physical process not only effectively eliminates indigenous species in ballast water, but also does not generate harmful by-products.

**Key words:** MPUV, Ballast water, Biological efficacy, Oxidants, Potential by-products

## INTRODUCTION

Ballast water provides stability to ocean-going vessels, and its uptake and discharge allow ships to compensate for cargo loads. Since it contains a variety of organisms, including indigenous plankton, bacteria and viruses, and large volumes of potentially contaminated ballast water are discharged to marine environment, ballast water is frequently considered as a major cause for the worldwide transfer of non-indigenous species. The International Maritime Organization (IMO) has established international regulations for the control and management of ship's ballast water and sediments, which regulate discharges of ballast water and reduce the risk of introducing non-native species from ship's ballast water (Lloyd's Register, 2010).

Medium pressure ultraviolet (MPUV) has been known as a disinfection process in drinking water and wastewater treatment. The MPUV lamps radiate polychromatically over a broad band of wavelengths (200–300 nm), which makes it possible to inactivate many marine species that have their

specific sensitive wavelengths (Giese and Darby, 2000). In a MPUV irradiation system, the photon flux is a key factor for the inactivation of harmful aquatic organisms. In addition to the photon flux, the MPUV irradiation can generate hydroxyl radicals (•OH), other residual oxidants, such as HOCl/OCl<sup>-</sup>, HOBr/OBr<sup>-</sup> and hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) (Cooper et al., 1988; de Mora et al., 2000). Once these oxidants are generated, they could react with dissolved organic matter in the water to form several harmful halogenated by-products, such as trihalomethanes (THMs), haloacetic acids (HAAs) and others.

This study aimed to evaluate the biological inactivation efficacy of several marine aquatic organisms and pathogens in ballast water and to investigate the potential formation of any oxidants and harmful by-products using a MPUV ballast water treatment system.

## METHODS

### Experimental set-up

The ballast water treatment system (GloEn-Patrol™ system, PANASIA Co. Ltd) (see **Fig. 1**) tested in this study was composed of filtration modules configured in parallel as a pre-treatment, followed by the MPUV process to inactivate the microorganisms present in ballast water. The flow rate was controlled to 250 m<sup>3</sup>/h for the land-based test (see **Fig. 2**). The test water was prepared using high salinity sea water at the coast of Busan (> 32 PSU) and brackish water at downstream point of the Nakdong River (20–22 PSU) depending on the required salinity.

### Biological efficacy test

For the biological efficacy test, marine organisms (> 50 μm and 10–50 μm size), *Escherichia coli* (*E. coli*) and the *Enterococcus* group were selected. In order to fulfill the biological water quality criteria of the IMO G8 guidelines, the mixture of indigenous organisms and the cultured surrogate species in laboratory (> 50 μm: *Artemia salina* and *Brachionus rotundiformis* (Rotifer), 10–50 μm: *Amphidinium carterae*, *Scrippsiella trochoidea* and/or *Tetralselemis spp.*) were added into the test water. The disinfection efficacy of this ballast water treatment system on marine organisms (10–50 μm or >50 μm) was evaluated by three kinds of measurement using a light microscope, an epifluorescence microscope and a

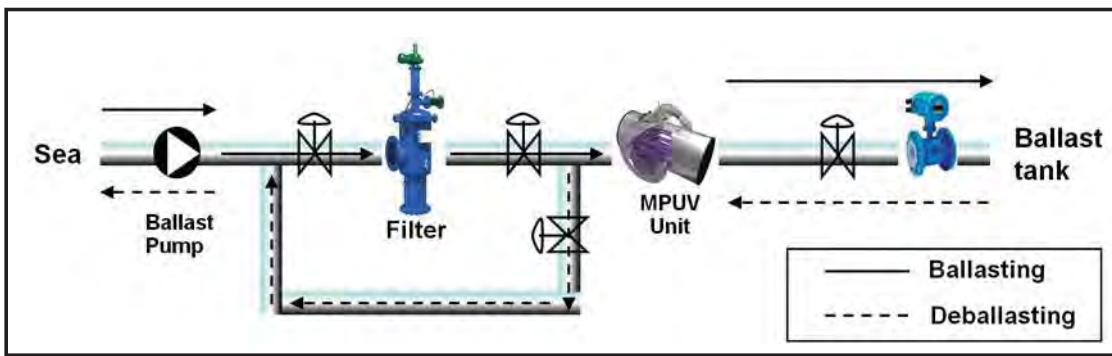


Figure 1. MPUV ballast water treatment system (GloEn-Patrol™)

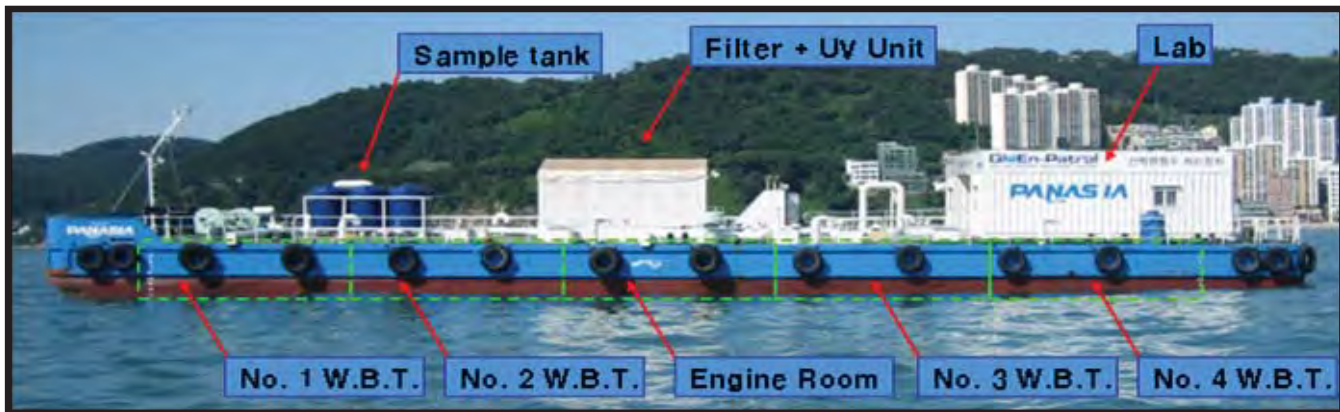


Figure 2. Land-based test facility

fluorometer. For *Escherichia coli* (*E. coli*) and Enterococcus, 10–40 mL of the sample was filtered on a 0.2  $\mu\text{m}$  membrane filter, and then the filters were incubated on the *E. coli* and coliform count agar plate or intestinal *Enterococci* agar plate for 24 h or 48 h at 35 °C.

## RESULTS AND DISCUSSION

### Biological efficacy test

The biological efficacy tests were performed at two different sites with more than 10 PSU difference in salinity for 5 days. After the MPUV treatment, the treated water and control water (i.e., non-treated water) were stored in a tank for 5 days, following which the numbers of viable organisms or microorganisms were counted.

The initial concentrations of the organisms for the group larger than 50  $\mu\text{m}$  and for the group between 10 and 50  $\mu\text{m}$  in size were  $1.8 (\pm 0.9) \times 10^5$  inds/ $\text{m}^3$  and  $1.9 (\pm 0.9) \times 10^3$  inds/mL, respectively, while the concentrations of *E. coli* and *Enterococcus* were  $5 \times 10^4$  and  $4 \times 10^2$  CFU/100 mL in the test seawater (see **Fig. 3**). After 5 days, 57–98% of organisms in the control water (non-treated water) were killed, while in the treated water most of organisms and microorganisms were inactivated to more than 99.99% of inactivation efficacy. Similarly, in the brackish water (see **Fig. 4**), high inactivation efficacies of more than 99.99% were observed for all tested organisms or microorganisms after the MPUV treatment.

### Formation of chemical oxidants and potential by-products

As shown in **Table 1**,  $\bullet\text{OH}$  and TRO were not detected in either the untreated or the treated water samples, which implies that the MPUV ballast water treatment system does not produce any secondary stable oxidants. As regards  $\text{H}_2\text{O}_2$ , a trace level (18–48  $\mu\text{g/L}$  in seawater) of residual  $\text{H}_2\text{O}_2$  was detected in the treated water samples after the MPUV treatment. However, knowing that the concentration level was in the  $\mu\text{g/L}$  range and that  $\text{H}_2\text{O}_2$  could be produced naturally by many living organisms, either within the organism itself or in the surround medium (*Anders et al., 1970*), therefore the concentration of  $\text{H}_2\text{O}_2$  formed during the MPUV treatment is not considered to be problematic in the marine aquatic environment.

Bromate ( $\text{BrO}_3^-$ ) and nitrate ( $\text{NO}_3^-$ ) which are known as toxic inorganic by-products, were not detected in any samples. In the seawater tests, halogenated organic by-products, such as THMs, HAAs, TCE, and PCE, were not detected in either the untreated or treated water samples. In the brackish water, however, low levels of HAAs were detected in both the untreated water (0.6–26.5  $\mu\text{g/L}$ ) and in the treated water (0.74–26.5  $\mu\text{g/L}$ ). These results arose from the contamination of the raw water with trace levels of HAAs, but were not formed as a result of the treatment.

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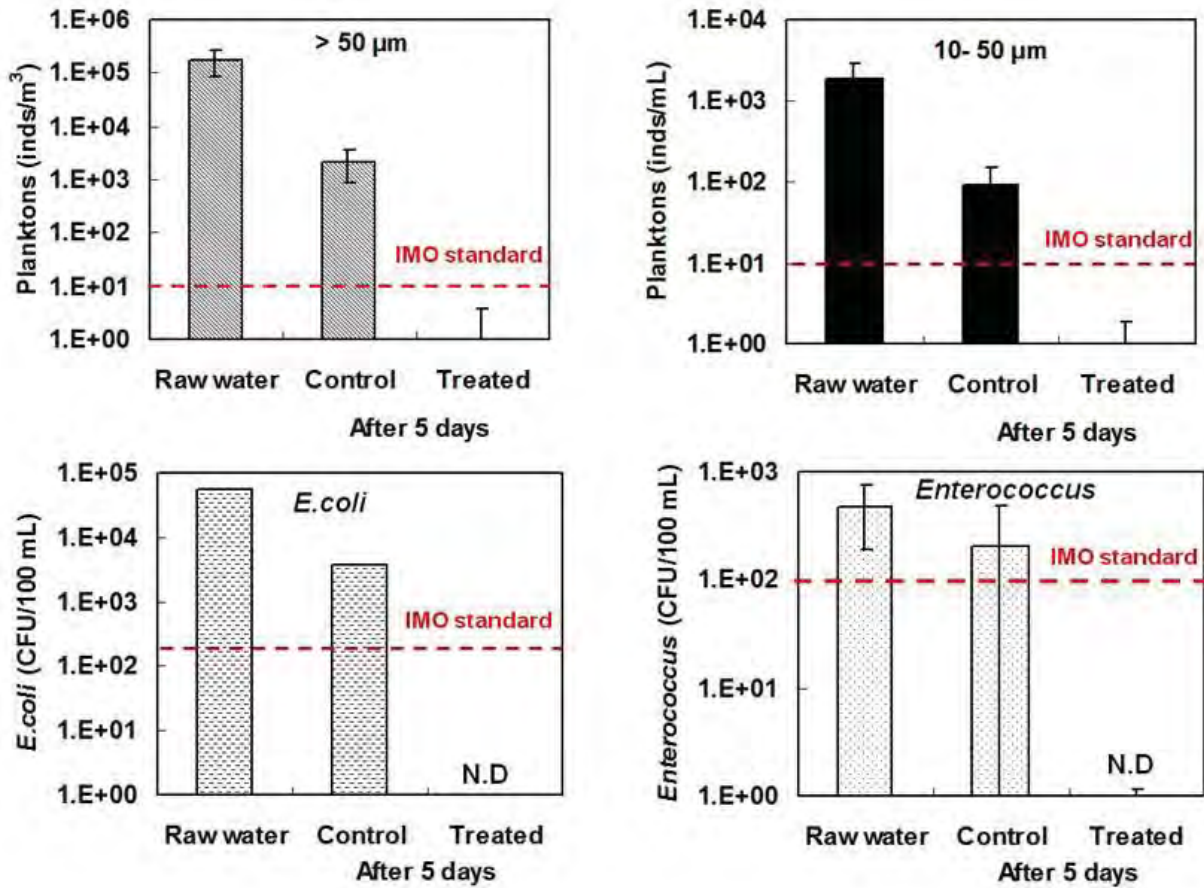


Figure 3. Biological efficacy: Seawater

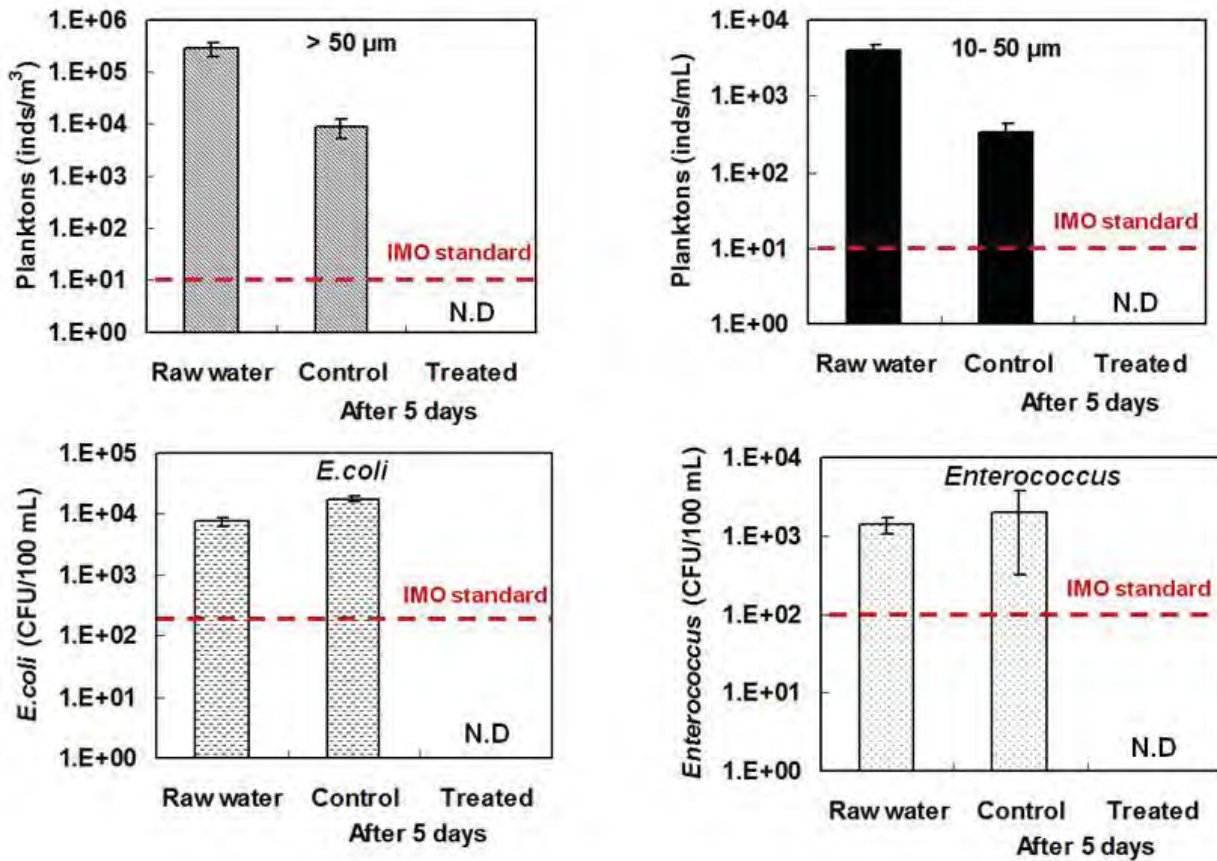


Figure 4. Biological efficacy: Brackish water



**Table 1. Formation of chemical oxidants and potential by-products (Seawater)**

Test period		Day 0		Day 3	Day 5	
Procedure		Ballasting		Storage (3 days)	Deballasting (after 5 days storage)	
Parameter	Unit	Untreated water	Treated water	Treated water	Untreated water	Treated water
•OH	μM	ND	ND	ND	ND	ND
TRO <sup>a</sup>	mg/L	ND	ND	ND	ND	ND
H <sub>2</sub> O <sub>2</sub>	μg/L	ND	48	ND	ND	18
BrO <sub>3</sub> <sup>-</sup>	μg/L	ND	ND	ND	ND	ND
NO <sub>3</sub> <sup>-</sup>	mg/L as N	ND	ND	ND	ND	ND
THMs <sup>b</sup>	μg/L	ND	ND	ND	ND	ND
HAAs <sup>c</sup>	μg/L	ND	ND	ND	ND	ND
TCE	μg/L	ND	ND	ND	ND	ND
PCE	μg/L	ND	ND	ND	ND	ND

a. TRO: Total Residual Oxidants, chlorine (HOCl/OCl<sup>-</sup>), bromine (HOBr/OBr<sup>-</sup>), mg/L as Cl<sub>2</sub>.

b. Chloroform, Bromodichloromethane, Dibromochloromethane, Bromoform

c. Dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, trichloroacetic acid.

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## CONCLUSIONS

The biological efficiency and formation of potential harmful by-products after the MPUV ballast water treatment were investigated for ballast water with various salinities. In the biological efficacy tests, indigenous species (>50  $\mu\text{m}$  and 10–50  $\mu\text{m}$ ) and surrogate microorganisms (*E. coli* and the Enterococci group) were tested. The results showed clearly that the organisms and microorganisms tested could be inactivated by the MPUV treatment showing more than 99.99% inactivation efficacy in both water matrices, and the biological efficacy successfully met the standard of International Maritime Organization (IMO). In addition, there were no residual oxidants in the treated water, except for  $\text{H}_2\text{O}_2$  (18–48  $\mu\text{g/L}$ ), and no harmful by-products were formed by the MPUV treatment in this system. In summary, the MPUV system is a clean and effective technology that can safely treat ballast water and does not affect the marine aquatic environment.

## KNOWLEDGMENTS

This study was supported by the Mid-career Researcher Program (2010-0014829) of the National Research Foundation (NRF) and the Brain Korea 21 Program of the Ministry of Education, Science, and Technology (MEST), Republic of Korea. We also thank PANASIA Co. Ltd. for their support and cooperation.

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# DRINKING WATER UV OPERATION WITHOUT ON-LINE UVT MONITORING: THE DEFAULT UVT AND SENSOR SETPOINT APPROACHES TO VALIDATION

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## ABSTRACT

UV reactors used in drinking water applications use an on-line UV dose monitoring algorithm to define disinfection performance. The USEPA UV Disinfection Guidance Manual describes two types of UV dose algorithms: the first is the calculated UV dose approach, which predicts the log inactivation or reduction equivalent UV dose (RED) as a function of flowrate through the reactor, the UV transmittance (UVT) of the water at 254 nm, the UV intensity measured by UV sensors, and lamp, row, or bank on/off status. The second is the UV intensity setpoint approach, in which case the reactor is in compliance with a required RED when the UV intensity measured by the UV sensors is greater than a required value defined as a function of flowrate through the reactor. A key benefit of the UV intensity setpoint approach is that no online UVT monitor is required, which is ideal for small or remote UV systems.

## INTRODUCTION

The UV intensity setpoint approach is validated by measuring the log inactivation and RED of a test microbe at various flowrates with the UVT and lamp power setting adjusted to provide specific UV sensor readings at the setpoint. Typically, the reactor is validated under two conditions of UVT and ballast power: maximum power and reduced UVT, and maximum UVT and reduced power. Depending on UV sensor position, the RED values measured at these two conditions may or may not be the same. The RED assigned to the reactor is the lower of these values.

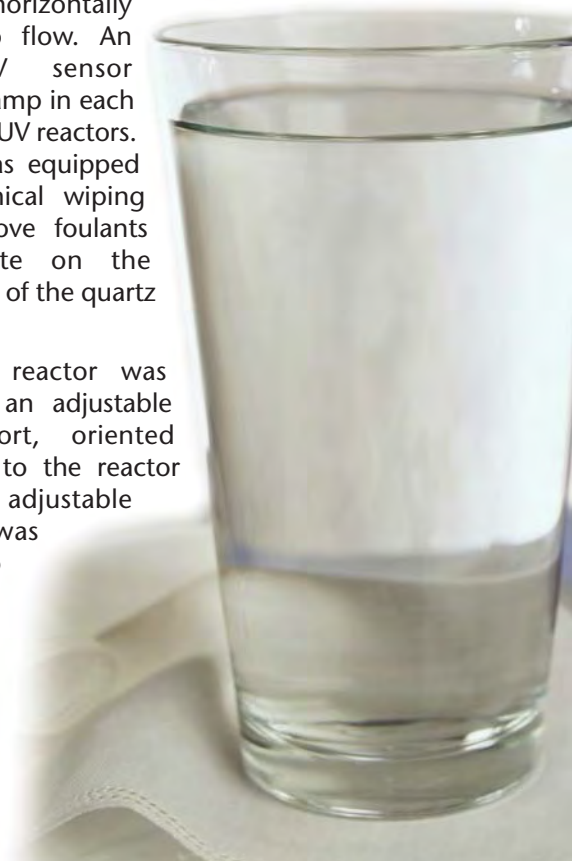
UV vendors will often validate their reactors knowing neither the relationships between the RED and the UV sensor response nor the impact of the UV sensor position on those REDs, which can lead to expensive iterative validation as the vendor works to identify the UV sensor readings required to achieve the required RED (e.g. 40 mJ/cm<sup>2</sup>) and to optimize the UV sensor position to minimize the differences between the REDs measured with the two test conditions. This approach also provides no information about REDs at UV sensor readings above and below the setpoint value or the relationship between RED and flowrate. In order to resolve these issues, Hanovia Ltd. of Berkshire, United Kingdom

developed a new approach for validating their ProLine series of in-vessel UV reactors using the UV intensity setpoint approach. The approach provides a UV dose algorithm that calculates RED as a function of flowrate and UV sensor reading but does not require an online UVT monitor.

## BACKGROUND

Three AF3 Series UV disinfection reactors, AF3 0014, AF3 0027 and AF3 0116, manufactured by Hanovia Ltd. of Berkshire, United Kingdom, were validated at a test facility located in Portland, OR. Each reactor was equipped with one low pressure high output amalgam lamp within an L-shaped cylindrical reactor with flanged inlet and outlet openings. The nominal power ratings for the AF3 0014, AF3 0027 and AF3 0116 UV reactor lamps were 140, 270 and 500 W, respectively. Each reactor's lamp was housed within a quartz sleeve that was oriented horizontally and parallel to flow. An individual UV sensor monitored the lamp in each of the three AF3 UV reactors. Each reactor was equipped with a mechanical wiping system to remove foulants that accumulate on the external surfaces of the quartz sleeve.

Each AF3 UV reactor was equipped with an adjustable UV sensor port, oriented perpendicularly to the reactor sidewall. The adjustable sensor port was designed to accommodate spacers of various lengths to result in different water layers, i.e. the distance between the quartz sleeve



*Continued on pg 24*



Continued from pg 23

and the UV sensor port window. UV sensor performance for each AF3 UV reactor was characterized during functional testing by evaluating the dependence of the measured UV intensity on ballast power, UVT, and water layer.

The validation data from the AF3 UV reactors was analyzed to develop an online UV dose-monitoring approach that requires UVT measurement input (the 'calculated UV dose' approach), as well as one that does not require UVT measurement input (the 'UV intensity setpoint' approach). Depending on the water layer, UV dose monitoring without input of the UVT can be more conservative than the calculated UV dose approach. In order to develop efficient UV dose monitoring algorithms for the AF3 UV reactors that do not require input of UVT measurement, the 'optimal' location for the individual reactor duty UV sensors was determined using the AF3 UV reactors' biosimetry data and UV intensity data.

To facilitate the prediction of the UV intensity for the AF3 UV reactors as a function of ballast operating power, UVT and water layer, UV intensity data was collected at three water layers with each AF3 UV reactor. The coefficients expressing UV intensity as a function of ballast operating power and UVT at each of the three water layers were then interpolated as a function of the water layer using polynomial interpolation in the Lagrange form. As a result of the interpolation, two general equations predicting the UV sensor readings for each AF3 UV reactor as a function of UVT, ballast power setting,

and water layer were developed:

$$S = 10^{A_{wl}} \times B_{wl}^{UVT} \times P^{C_{wl}} \times D_{wl}^P \quad [1]$$

$$A_{wl}, B_{wl}, C_{wl}, D_{wl} = a \times (b \times wl) \times (c \times wl^2) \quad [2]$$

where:

$S$  = measured UV intensity ( $W/m^2$ )

$P$  = ballast power (W)

$wl$  = water layer between UV sensor and quartz sleeve (mm)

$A_{wl} - D_{wl}$  = empirically-determined coefficients (see **Table 1.1**) for a given water layer

$a - c$  = empirically-determined coefficients (see **Table 1.1**)

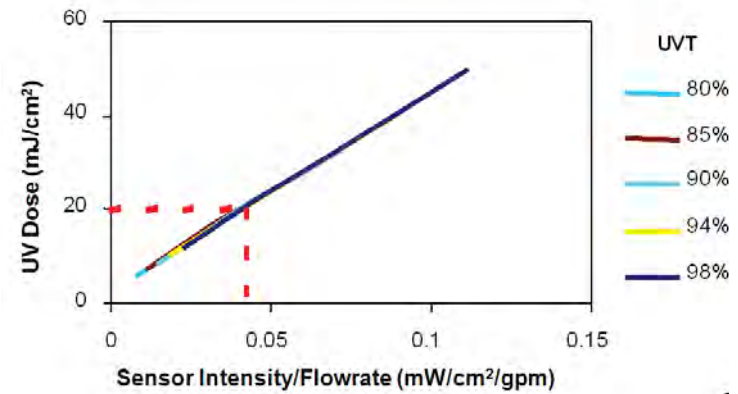
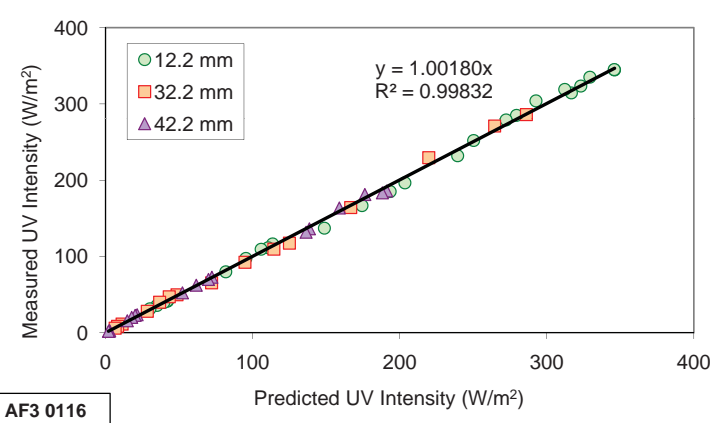
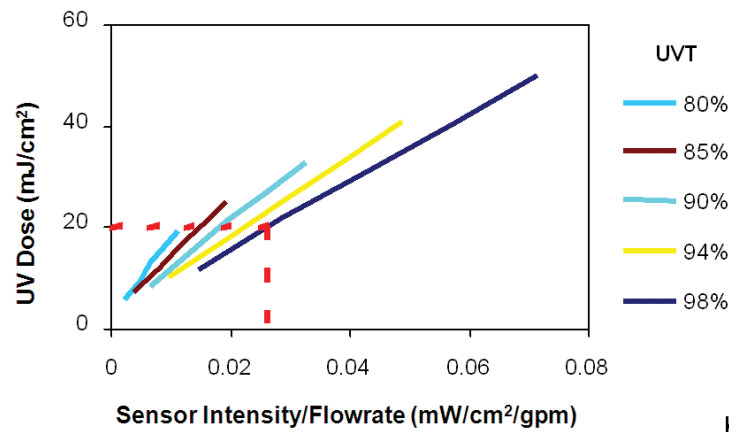
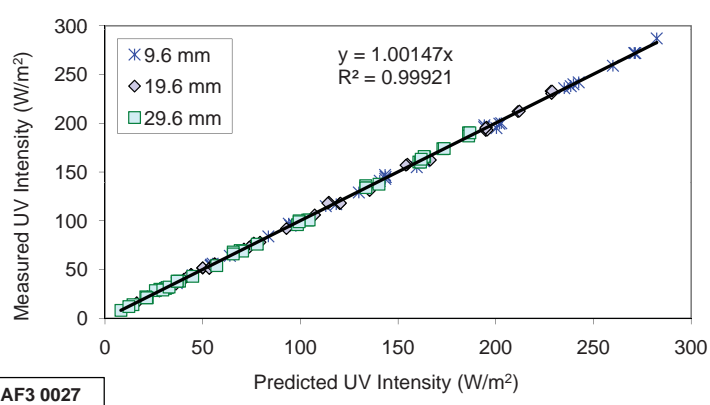
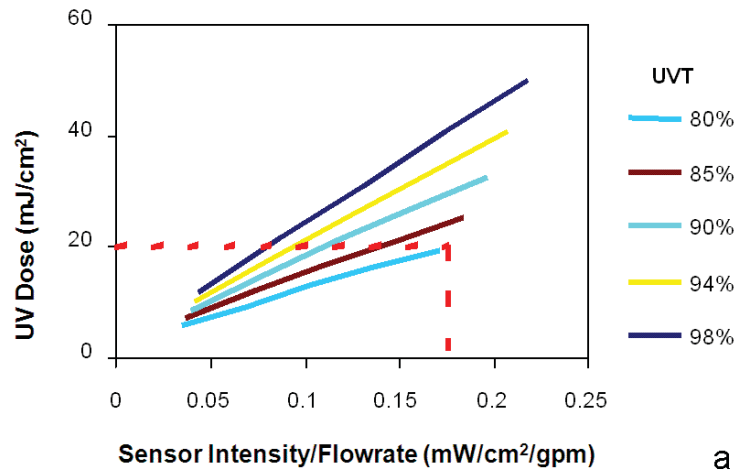
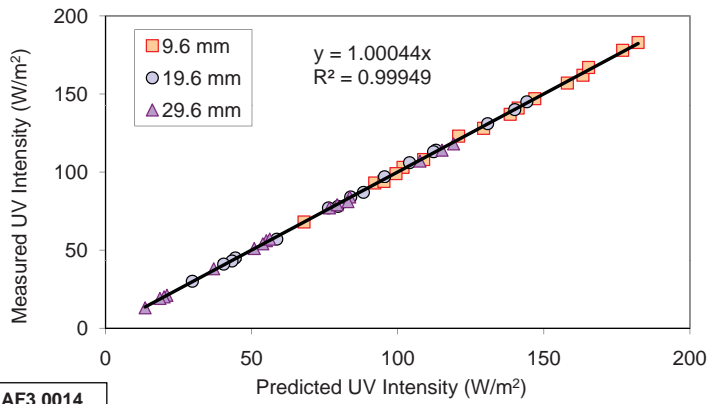
**Fig. 1** shows the relationship between the UV intensity measured by the AF3 UV reactors' duty UV sensors, at three water layers, and the UV intensity predicted using **Equations 1 and 2**. The prediction residuals, calculated as the difference between the measured and predicted UV sensor readings divided by the predicted UV sensor reading, showed low variability, with a maximum standard deviation of 5.1 percent, and were randomly distributed around zero, with an average of 0.0 percent.



UV validation at the Portland test facility has a global impact on UV implementation

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**Figure 1:** Predicted versus measured UV Intensity for the AF3 UV reactors (the reactor number is in the lower left corner of each chart).

**Figure 2:** Relationship between the MS2 RED and the measured UV intensity divided by the flowrate for three sensor positions with a hypothetical UV reactor (Wright et al., 2002); (a) sensor close to lamp; (b) sensor far from lamp; (c) optimal sensor position.

Continued on pg 26

# OPTIMAL WATER LAYER ANALYSIS

The relationship between the RED, UV intensity ( $S$ ), and flowrate ( $Q$ ) varies based on the combination of the UVT and the water layer (Wright et al., 2002). Based on the UV intensity setpoint approach, if the UV sensor is located at an 'optimal' distance from the monitored lamp, the relationship between RED and UV intensity divided by flowrate ( $S/Q$ ) for various water UVT values will overlap (**Fig. 2**). If this is the case, the combined dataset for various UVT values can be described by a single function, which can be used for UV dose monitoring over the validated range of UVT. However, if the UV sensor is located at a water layer other than this 'optimal' position, the relationship between the RED and  $S/Q$  will not overlap and will depend on UVT. If the UV sensor is located relatively close to the lamps, the RED will be proportional to the UVT. However, if the UV sensor is located relatively far from the lamps, the RED will be inversely proportional to the UVT.

The biosimetric testing of both the AF3 0014 and AF3 0027 reactors was conducted with a water layer of 18.5 mm, while biosimetric testing of the AF3 0116 reactor was conducted with a water layer of 32 mm. With all three reactors, the RED at a given value of  $S/Q$  tended to increase proportionally with UVT, suggesting that the UV sensor was closer to the lamps than the optimized location. The increase was most notable with the AF3 0014 and less so with the AF3 0027 and AF3 0116 reactors.

The relationship between the MS2 RED and the predicted  $S/Q$  was used to identify a calculated estimate of the optimized UV sensor water layer based on the logistical constraints of equipment manufacturing. In practice, this calculated distance minimized the residuals between the predicted and measured REDs and resulted in optimal water layers of 23 mm for both the AF3 0014 and AF3 0027 reactors and 32 mm for the AF3 0116 reactor. In the latter case, the water layer used during biosimetry (32 mm) was determined, after the fact, to be close to the optimal location for the duty sensor.

# CALCULATED UV DOSE MONITORING ALGORITHM ANALYSIS

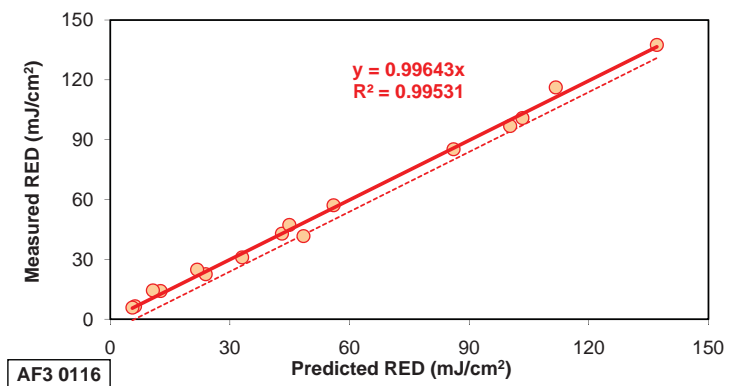
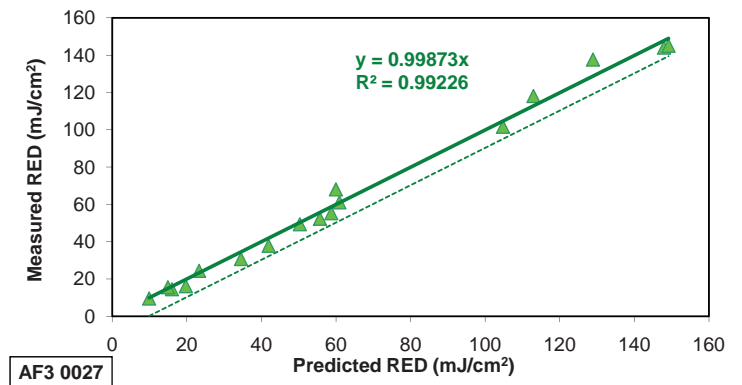
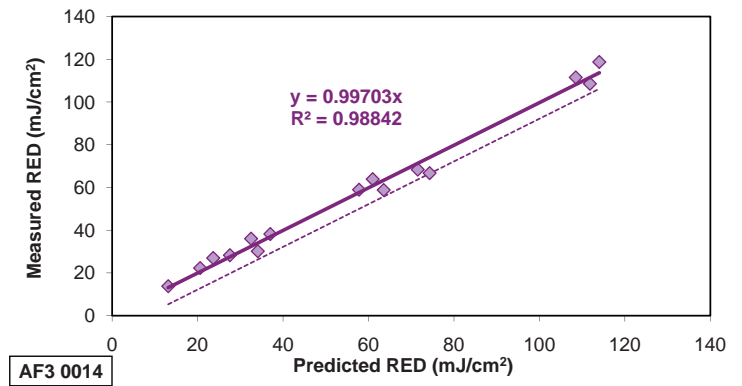
For calculated UV dose monitoring with each AF3 UV reactor, the measured MS2 RED ( $\text{mJ}/\text{cm}^2$ ) was best expressed as a function of relative lamp output (at the determined optimal water layers), flowrate (mgd) and absorbance (UVA) at 254 nm:

$$\text{MS2 RED} = e^{-A} \times \text{UVA}^{B \times \text{UVA}} \times \left[ \frac{S}{Q} \frac{S_0}{Q} \right]^{[C-D \times \ln(\text{UVA})]} \quad [3]$$

where

$S/S_0$  = relative lamp output, calculated as the ratio of the measured UV intensity,  $S$  ( $\text{W}/\text{m}^2$ ), to the UV intensity predicted with the lamp operating at maximum power, given the measured UVT, with Eqs. 1 and 2,  $S_0$  ( $\text{W}/\text{m}^2$ )

$$\text{UVA} = \log(\text{UVT}_{254}/100)$$



**Figure 3:** Predicted versus measured REDs for the AF3 UV reactors: calculated UV dose approach (the reactor number is in the lower left corner of each chart).



**Fig. 3** shows the relationship between measured and predicted REDs using Eq. 3 for the three AF3 UV reactors. The data was fit with a linear function forced through the origin (0,0), and the R squared coefficient of determination for the fits were all at least 0.99, indicating a strong correlation between the measured and predicted RED values. The lower 95 percent prediction intervals are shown as dashed lines, calculated as described in Section 5.9.2.2 of the UVDGM. The average and standard deviation of the prediction residuals (which were calculated as the difference between the predicted and measured RED) were 0.0 and 3.6 mJ/cm<sup>2</sup>, 0.0 and 4.6 mJ/cm<sup>2</sup>, and 0.0 and 2.9 mJ/cm<sup>2</sup> for the the AF3 0014, AF3 0027 and AF3 0116 reactors, respectively.

## UV DOSE MONITORING WITHOUT UVT INPUT

Nominal lamp output,  $S_0$ , is a function of the UVT, and, as a result, the RED (as predicted by Eq. 3) is a function of  $S$ ,  $Q$  and  $UVT$ . In order to develop a UV dose monitoring approach for each AF3 UV reactor that does not require  $UVT$  measurement, Eq. 3 (using optimal water layers) was used to predict the MS2 REDs at discrete  $S/Q$  values, which spanned the validated range of  $S/Q$ . At each of these  $S/Q$  values, the RED was calculated across the validated UVT range.

In order to define a conservative UV dose monitoring approach without on-line UVT measurements, the minimum REDs predicted at each discrete  $S/Q$  value, across the validated UVT, were plotted as a function of the corresponding  $S/Q$ . The relationship between minimum predicted MS2 REDs and the  $S/Q$  for each AF3 UV reactor were best fit with a fifth order polynomial equation:

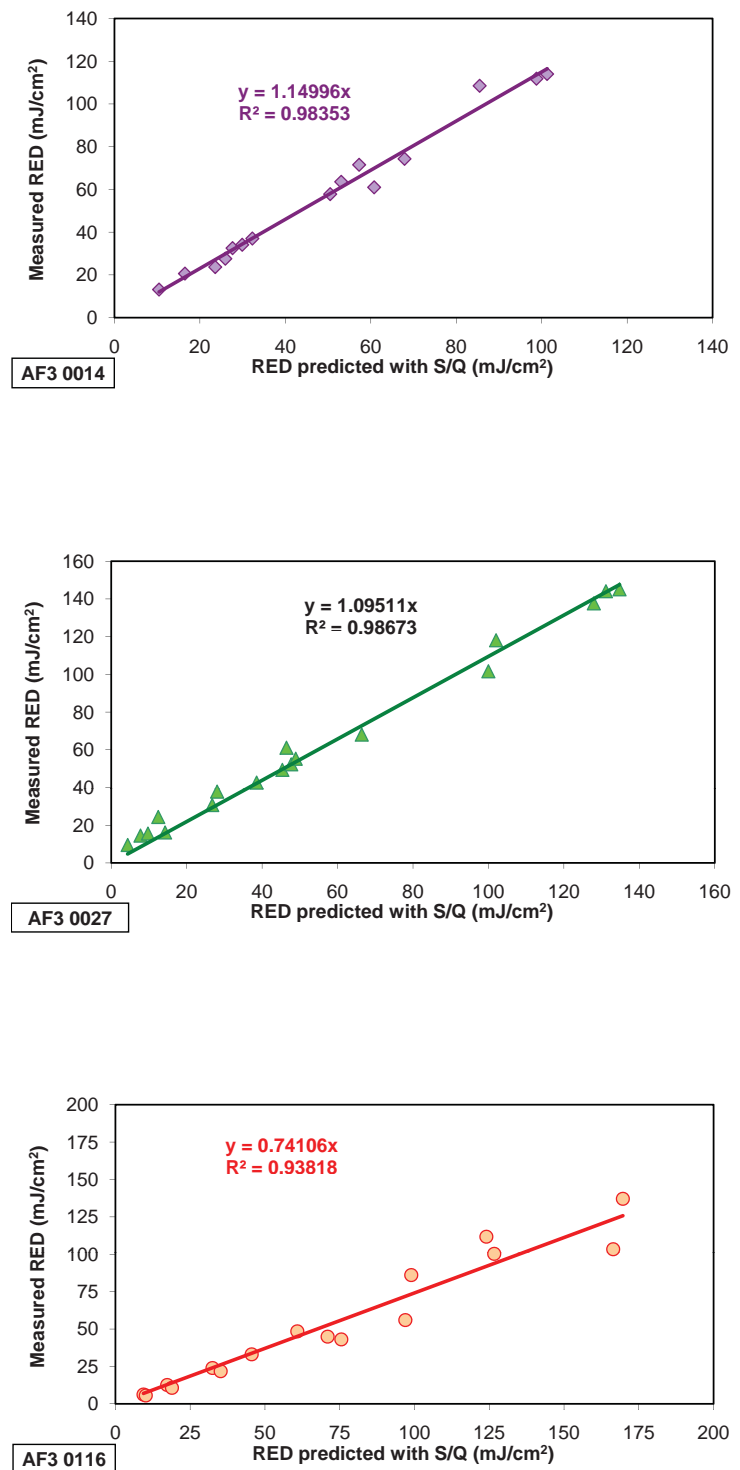
$$RED = A \times \left[ \frac{S}{Q} \right]^5 + B \times \left[ \frac{S}{Q} \right]^4 + C \times \left[ \frac{S}{Q} \right]^3 + D \times \frac{S}{Q} + E \quad [4]$$

**Fig. 4** shows the relationship between measured and predicted REDs using Eq. 4 for the three AF3 UV reactors.

Since the RED values input into Eq. 4 are the minimum REDs for a given  $S/Q$ , they provide a conservative dose monitoring approach across the validated range of UVT (**Fig. 4**). As mentioned above, the water layers matched the optimal, calculated location to manufacturing constraints. Theory suggests that use of this equation outside the validated range of UVT, though considered an extrapolation, will still provide conservative UV dose monitoring for the AF3 UV reactors.

The UV dose monitoring approach was approximately 10, 15 and 26 percent conservative for UV dose monitoring compared to validation for the AF3 0014, AF3 0027 and AF3 0116, respectively, indicating that the water layer was more optimized for the AF3 0014 and AF3 0027 reactors than for the AF3 0116 reactor. The nominal lamp power rating of the AF3 0116 reactor was almost twice that of the AF3 0014 and AF3 0027 reactors and was validated at flows that were at least seven times greater than those of the AF3 0014 and AF3

0027 reactors. As a result, the validated range of  $S/Q$  for the AF3 0116 reactor spanned two orders of magnitude, while the same for the AF3 0014 and AF3 0027 reactors spanned only one order of magnitude. Because of this difference in validated range, the AF3 0116 reactor has potentially several optimal sensor locations, depending on the  $S/Q$  value.



**Figure 4:** Predicted versus measured MS2 REDs: UV dose monitoring without UVT (the reactor number is in the lower left corner of each chart).

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## SUMMARY

Validated calculated UV dose algorithms can be used to develop online UV dose monitoring strategies that do not require UVT input. The DVGW approach uses 'low' and 'high' UV intensity setpoints to develop the a UV intensity setpoint UV dose monitoring approach; however, outside of these two points, the reactor performance may no longer be consistent. The use of calculated UV dose algorithms to develop UV intensity setpoint UV dose monitoring strategies better defines UV dose delivery between the 'low' and 'high' points, as multiple data points are used in the assessment.

Online UVT monitors tend to drift over time, so their accuracy needs to be checked regularly using calibrated bench-top UV spectrophotometers. Depending on the water layer, the online UVT drift can result in significant UV dose calculation error, especially in high UVT water. As a result, algorithms that forgo UVT measurements eliminate UV dose calculation uncertainty as well as off-spec performance associated with UVT monitors, reducing UV system O&M requirements.

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# UV FAQ'S

*Editor: I often get questions about UV. The following are some recent interesting items.*

## QUESTION:

The equipment UVB(5%), UVC(75%) therapy unit I have used in my study had a the term as "INTENSITY = 5 mJ/s/cm<sup>2</sup>". I have used the duration of exposure over a 9 cm Petri dish for maximum of 30 seconds. I need to know whether the exposure is within exposure limits or not. I got in one reference, exposure limit as 1-3 minutes for germicidal lamp – with this criterion, I am well within the limit. But when we consider 30 J/m<sup>2</sup> for 8 hour period, am I still within the exposure limits or not? Please explain to me this parameter. (from Bhamini)

## ANSWER:

'Intensity' is meaningless unless the distance (in cm) is specified from the source to the detector. The normal units for 'intensity' (better called 'irradiance') are mW/cm<sup>2</sup>. UV dose (mJ/cm<sup>2</sup>) is approximately the product of the average irradiance (mW/cm<sup>2</sup>) and the exposure time (s). In your case, the situation is more complex, since you have a polychromatic light source, and all UV detectors have a sensitivity that depends on the wavelength.

## QUESTION:

I am required to test the output of my UV lamp in my water bacteriology lab. My UV meter measures in microwatts/cm<sup>2</sup>. My UV lamp is rated at 365 nm. I have to measure the output quarterly to ensure it is putting out 365 nm or otherwise install a new lamp. I don't how to readily convert microwatts/cm<sup>2</sup> to nm. Help please. (from Mark)

## ANSWER:

First you need to understand that irradiance (microwatt per sq. cm) and wavelength (nm) are two quite different things - you cannot 'convert' from one to the other.

Your lamp is emitting at a wavelength of 365 nm, and, as I understand it, your radiometer and detector (I presume it is calibrated at 365 nm?) reads 'irradiance'. The irradiance at a certain distance from the lamp will be proportional to the lamp output, so if you make regular measurements, and you observe a decrease, this could indicate that you should replace the lamp.

## QUESTION:

I am concerned about ultraviolet radiation; can it cause ill effects similar to that from radiation in nuclear reactors? (from Wanda)

## ANSWER:

I prefer to use the term 'UV light' rather than 'UV radiation' for the very reason that you are confused. Ultraviolet is 'light' – you can't see it because our eyes are not sensitive to UV; however, it is a form of light with wavelengths beyond the 'violet' end (hence the term 'ultraviolet') of the rainbow spectrum.

Since UV is 'light', it travels through air and water at the speed of light, and when the UV source is turned off, the UV is gone. There are no 'residuals', and the water that has been exposed to UV is the same as it was before exposure, and certainly the water is not 'radioactive'. It is like shining a bright light into a glass of water. I think you would agree that when you turn off the light, the water has not changed.

UV water disinfection units are designed to provide enough 'UV dose' so that any pathogenic microorganisms in the water are rendered 'inactive'. What happens is that the UV is absorbed by the DNA in microorganisms; the DNA is damaged so that the microorganisms cannot reproduce. Cells that cannot reproduce cannot cause disease. The beautiful thing about UV is that it does its job while the water is passing through the unit, but after the water has passed through, it has been 'disinfected', but its 'water quality' has not changed.

## QUESTION:

Are there a material safety data sheets for ultraviolet lamps? (from John)

## ANSWER:

There are several available on the web, such as

[http://www.homedepot.com/catalog/pdfimages/ea/ea00322d-70ed-47c8-93c8-d0eeb6e831a7.pdf?cm\\_mmc=seo|altruik|202520794](http://www.homedepot.com/catalog/pdfimages/ea/ea00322d-70ed-47c8-93c8-d0eeb6e831a7.pdf?cm_mmc=seo|altruik|202520794)

<http://www.piercenet.com/msds/EN7636.pdf>

[http://www.uvlamp.com/msds/MERCURY\\_UV\\_LAMPS/MSDSlamps.pdf](http://www.uvlamp.com/msds/MERCURY_UV_LAMPS/MSDSlamps.pdf)

There is also a good article on Ultraviolet Safety.

## QUESTION:

When a Medium Pressure UV lamp is used to disinfect seawater, is any secondary oxidant (e.g., OH radicals, hydrogen peroxide, etc) that might affect ecology formed? If so, what are they then? (from Joon)

## ANSWER:

If the UV dose applied is about 40 mJ/cm<sup>2</sup>, which is the recommended UV dose to achieve at least 4 logs (99.99%) inactivation of almost all bacteria, viruses and protozoa, then any 'photolysis' of the water will be negligible. The UV dose required to achieve photolysis of dissolved components in the water is at least 50 times higher than that required for UV disinfection.

## QUESTION:

I've been researching air purification systems. I'm looking at two systems based on Photocatalytic Oxidation. Company A and Company B.

- Company A uses a 3-year UV bulb that needs to be disposed of as hazardous waste due to small amounts of mercury contained.
- Company B uses a 1-year lifetime UV bulb and has no mercury warning. I have gotten mixed info when talking to the company and doing my own research about UV and mercury.
- Is it true that ALL UV bulbs contain some amount of mercury?
- Is it possible that Company A's bulb has none? I am sure that that this company does not mention it in their literature on the bulb, and indicate no requirement for special disposal.

I'd appreciate any info you can provide to help me understand what I'm purchasing and make the choice best for me... I am not comfortable with the idea of mercury in something that could break or having to dispose of a bulb as hazardous waste (from Lauren).

## ANSWER:

Almost all UV lamps contain small amounts of mercury. I suspect that the UV lamps in the products you mention are low pressure UV lamps. These are essentially the same as fluorescent lamps – the only difference is that a UV lamp has a quartz envelop, whereas a fluorescent lamp has a glass envelop with a phosphor on the inside that absorbs the 254 nm from the mercury emission and re-emits visible light. Hence the safe disposal procedures for low pressure UV lamps are the same as that for fluorescent lamps.

# LARGE-SCALE DISINFECTION

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