FEATURES

Early Adoption of UV-C Light Emitting Diode Technology for Water Disinfection

Cycle Costing of UV-based Treatment of Emerging Contaminants

Optimizing efficiency of Low-Pressure Lamp UV Systems

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Phyllis B. Posy, Atlantium Technologies

Editor-in-Chief
Deborah Martinez
deb.martinez@iuva.org

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IUVA Executive Operating Committee
President: Paul Swaim, P.E.
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Regional Vice President (Asia):
Rongjing Xie, Ph.D.

IUVA Head Office
Deborah Martinez
Executive Director
International Ultraviolet Association
1718 M Street, N.W., #276
Washington, D.C. 20036
(202) 422-2445
(202) 318-4561 (fax)
deb.martinez@iuva.org

FALL 2012
Many of us were excited to join in the Americas Regional Conference, “Moving Forward: Sustainable UV Solutions to Meet Evolving Regulatory Challenges,” that was held in Washington, D.C., in August. It was a conference chock full of enlightening information. It was also great to meet and network with all of our colleagues who are leaders in the many facets of the growing ultraviolet industry.

This conference represented the aggressive approach that IUVA is taking to reaching out to all facets of the ultraviolet technology industry and assuming our fitting role as the leader in the research and application of UV technology worldwide.

We have events and conferences scheduled over the next year that include a workshop with NASA in Washington, DC, on October 26-27, 2012, a seminar at the IWA disinfection conference in Mexico City on November 25, 2012, (our first outreach event with Wenjun Liu, Director of the IUVA Asia/Australia HUB), a 2-day regional conference in Karlsruhe, Germany on June 4-5, 2013, and then our Third World Congress in Las Vegas on September 22-25, 2013. Mark your calendars and try to attend as many as possible to stay up to date on our evolving industry. For information about any of these meetings, go to the IUVA website at iuva.org.

Meanwhile, we continue with our efforts to integrate best practices in our administrative operations, especially with our financial affairs. This effort is paying off with a membership that continues to grow and with increasing interest in our conferences and events.

While most of us are focused on our day jobs, IUVA is pleased to benefit from the collaboration of our members worldwide, and we are very grateful to those who dedicate so much of their time to help make IUVA the wonderful organization that it is today.

We are developing very good momentum with successes throughout many of our endeavors, and we hope to keep up that track record of creating a growing and ever-stronger IUVA.

Thank you one and all for your support.

–Paul Swaim
With joys of summer now becoming a distant memory, IUVA leadership is gearing up for an even more aggressive schedule for the coming months.

First, I want to recognize the success of the Americas Regional meeting, “Moving Forward: Sustainable UV Solutions to Meet Evolving Regulatory Challenges,” that was held in Washington in August. Some 190 engineers, government officials, academicians and students from around the world attended the conference. While anecdotal reports were that the conference content, in particular, received high marks, we are conducting a survey to get your feedback on the conference so that we can plan better conferences, meetings and webinars in the months to come. I encourage you to participate in the survey by visiting https://www.surveymonkey.com/s/WashingtonEvent.

We are now focused on upcoming conferences and meetings, which will include:

- IUVA and the National Aeronautics and Space Administration (NASA) are teaming up to inspire high school seniors and college students to widen their knowledge in science, technology, engineering and math (STEM) at a special NASA Space Science Workshop in Washington, D.C., Oct. 26-27, 2012,
- The “Basics of UV Disinfection for Water, Wastewater and Reuse Applications” conference in Mexico City on Nov. 25, 2012,
- The IUVA Asia-Australia Workshop on UV disinfection technologies applied to water and wastewater treatment in Beijing Dec. 18, 2012,
- The EMEA Regional Meeting that will be held in Karlsruhe, Germany, June 4-5, 2013, and
- The Third Annual World Congress that will be held in Las Vegas Sept. 22-25, 2013.

We expect and plan for each meeting to increasingly attract more and more participants through high-quality programming, outstanding speakers, careful venue and agenda planning and substantial corporate sponsorship. The result will be the enhancement of the value of the IUVA brand and the expansion of the IUVA leadership role in research and the application of UV technology.

One special strategic initiative that we are developing and which we will incorporate into future conferences and meetings is continuing education. There is a growing demand for training and education, along with certification, in the use and application of UV technology. And IUVA is positioned strategically to meet this growing demand. Training, education and certification provide important opportunities for IUVA to demonstrate its leadership in UV technologies, and we fully intend to take advantage of these opportunities.

Meanwhile, we are also working to strengthen our administrative operations through the development of a strategic business plan. The management of the IUVA organization and the implementation of its many initiatives is an operation that is evolving and becoming increasingly complex. It must become more and more sophisticated. Consequently, we must put in place the fundamental management tool of a strategic business plan, so that we define who we are, where we are going and how we are going to get there. We expect to have a plan ready for approval by the end of the calendar year.

We also continue to focus on efficient business practices in the management of our financial resources and membership. Through timely and accurate billing procedures, we have brought many lapsed members back to current status with the payment of dues, and we continue to recruit more and more new members. This results not only in increased revenue, but also with an improve public awareness of the solid business practices of the organization. In the coming year, our plan is to reach out to government and industry officials, as well as to students, to recruit more members.

As usual, none of this could be accomplished without the collaboration of the leadership of IUVA and the many members who have been so supportive. I thank all of you for your assistance.

Please feel free to contact me with any suggestions, inspirations and comments about how IUVA can continue to grow and succeed. I look forward to hearing from you.

All best wishes.

—Deb Martinez
REPORT from IUVA

BERTRAND DUSSELT: DIRECTOR OF THE IUVA AMERICAS HUB OFFICE

I am happy to report that the 2012 Americas conference, held in Washington, D.C., last month, was a very successful event. I continue to receive feedback from attendees, who enjoyed the excellent quality of the technical program. The keynote speaker, Stig Regli, Senior Leader/Policy Advisor for EPA’s Office of Ground Water and Drinking Water, kicked off the conference by framing its major theme “Moving Forward: Sustainable UV Solutions to Meet Evolving Regulatory Challenges”. As for all IUVA events, the interest remained high for the latest industry developments in the drinking water, wastewater, water reuse and AOPs markets. But the attendees’ curiosity spiked with sessions on emerging technologies, with an entire session on UV LEDs (a first at an IUVA event), and applications such as air treatment, industrial water, and aquatics. The Panel Discussion on “Surrogates: Impact on Validation” generated a lively discussion on the latest developments related to the use of surrogate organisms as the industry continues to refine procedures based on new science. Last but not least, I was encouraged by the excellent work presented by students. The IUVA has a bright future!

It is now time to focus on our next exciting event, our first ever workshop in Mexico. The workshop, to be held on November 25th and in conjunction with the International Water Association (IWA) Disinfection Conference, will focus on “Basics of UV Disinfection for Water, Wastewater and Reuse Applications”. The program includes a stellar lineup of speakers, including representatives from leading consulting engineering firms (Carollo Engineers), universities (Medical University of Vienna), and suppliers (Trojan Technologies, Aquionics, and Calgon Carbon). You can find more information on this event, including the program, at http://iuva.org/event/basics-uv-disinfection-w

As always, I welcome your thoughts on all the above initiatives, and any other relevant topic you want to share with me; it will be great to hear from you at americas@iuva.org.

–Bertrand Dussert

STUDENT WINNERS FOR PAPERS AND POSTERS AT AMERICAS REGIONAL MEETING IN WASHINGTON AUG. 12-14.

Kati Bell, Ph.D., P.E., IUVA Treasurer; Sara Beck, a graduate student working on her Ph.D. at the University of Colorado; Austa Parker, a graduate student working on her Ph.D. also at the University of Colorado; and Karl Linden, Ph.D., faculty member at the University of Colorado and President-Elect of IUVA. Ms. Beck won Second Place for student papers and posters, and Ms. Parker won First Place. In her studies, Ms. Beck is focusing on UV Disinfection, and Ms. Parker is focusing on UV Advanced Oxidation.

ShihChi Weng, a graduate student working on his Ph.D. at Purdue University, and Kati Bell, Ph.D., P.E., IUVA Treasurer. Mr. Weng won Third Place for student papers or posters.

Photos by Charles Jackson
Introducing the Duron, Wedeco’s latest offering for open channel waste water UV disinfection. With more than 20 years of vertical UV disinfection engineering & research behind its design, the Duron is shining new light on wastewater treatment. Duron systems take the latest Ecoray high powered energy efficient lamps and incline them at a 45 Degree angle, saving additional space in the channel. It’s integral lifting device allows for easy maintenance and accessibility, making it a clear choice in terms of ease of operation. Find out why the Duron is making waves @ www.wedeco.com
The IUVA and the German TZW (Technology Centre for Water) have begun work to organize the regional Congress in Karlsruhe, Germany, June 4-5, 2013. Visit www.iuva.org to get information about the call for papers for the conference. Exhibitors and sponsors are invited to give five-minute presentations about their newest releases and innovations. The Congress will specifically target the water arena, and we welcome any application around drinking- waste- and industrial waters; AOP; ballast water and water reuse with respect to UV technologies and applications. The venue will be at the Karlsruhe Congress Centre, and you can also choose from a variety of nearby hotels in different price categories. Reservation forms can be downloaded from the IUVA website. Early bird registration will be online shortly as well. Please contact me directly or the IUVA headquarters if you have any questions or comments.

Our one-day workshop at the UNESCO IHE in Delft in June was very well received. Attendees enjoyed a world-class program with lots of information and ideas about UV technologies with a special focus on the need for and the difficulties of decentralized treatment concepts in emerging countries. UNESCO IHE representatives are considering making the one-day event a part of their educational program.

The BSH (the German Federal Maritime and Hydrographic Agency) in Hamburg contacted us about the possibility of organizing a follow-up event on the ballast water workshop we held last December. This is most likely going to happen in January or February 2013. Stay tuned for updates.

We are exploring the possibility of holding workshops in Spain and France on the involvement of UV in water reuse projects and, in particular, for drinking water applications. If you would like to support these activities, please contact me at your earliest convenience.

- Andreas Kolch

The following is a summary of the major activities conducted by the Asia and Australia Hub Director.

The Asia and Australia Hub Director attended the IUVA “Moving Forward: Sustainable UV Solutions to Meet Evolving Regulatory Challenges” Conference on Aug. 12-14 in Washington, D.C. and met with the IUVA Executive Operating Committee to discuss future plans for the IUVA Asia and Australia Hub.

Professionals from the UV industry were encouraged to prepare papers for the third annual World Congress in Las Vegas, Nevada, Sept. 22-25, 2013, and to plan to attend the conference.

Planning for the IUVA Asia-Australia Workshop Dec. 18, 2012, in Beijing continued. The Workshop is expected to attract 100 attendees. It will focus on UV disinfection technologies applied in water and wastewater treatment in China.

Jiangsu Juguang Photoelectric Technology Co., Ltd (http://www.jsjuguang.cn/en/) has joined IUVA.

The Asia and Australia Hub Director was elected a fellow of IWA and will attend the IWA Congress in Busan, Korea this month.

– Wenjun Liu
Designed for the most challenging wastewater reuse and low-effluent-quality applications, Calgon Carbon’s C3500™D UV disinfection systems feature unique Delta Wing mixing devices that maximize efficiency while minimizing costs.

Our patent-pending C3500™D design features:
- High-powered (500W) lamps
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- Automatic self-cleaning to enhance energy efficiency
- NRWI validation for reuse applications

Independent testing has demonstrated the value of the C3500™D UV disinfection system:
- Lower power costs
- Lower installation and O&M costs

Calgon Carbon UV Technologies: The Clear Choice
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NEOTECH AQUA SOLUTIONS OFFERS NEW PRODUCT DATA SHEETS

NeoTech Aqua Solutions, the industry leader in High-Efficiency Ultra-Violet (UV) water treatment systems, announces the release of newly updated product data sheets detailing the practical advantages and technical specifications for NeoTech’s disinfection and TOC-reduction lines of UV systems.

The updated product sheets may be viewed and downloaded at neotechaqua.com. Hard copies and pre-assembled engineering manuals for the NeoTech Aqua product line are also available and may be obtained by calling NeoTech’s customer service department at 858-571-6590 or emailing cjimenea@neotechaqua.com.

NeoTech Aqua Solutions specializes in the development, manufacturing and sales of High-Efficiency UV Systems for disinfection and TOC reduction in water treatment plants. Since 2002, the company has secured multiple patents on UV technologies which reduce power consumption, space requirements and operational costs by up to 90% compared to standard UV systems. For more information on the NeoTech Aqua Solutions line of high-efficiency UV systems, visit the company on the web at NeoTechAqua.com or call 858-571-6590.

NEW THIRD EDITION OF ‘UV GUIDELINES’ PROVIDES UPDATED PROTOCOL FOR TESTING AND VALIDATING UV PERFORMANCE IN WATER TREATMENT


These guidelines provide regulatory agencies and water and wastewater utilities across the country with a common basis for evaluating and implementing ultraviolet (UV) disinfection, which is a key technology used in the treatment of water. UV treatment can inactivate many waterborne pathogens, such as viruses, bacteria, and parasites like cryptosporidium and giardia. Unlike chemically based disinfection options, UV disinfection does not produce potentially harmful disinfection byproducts during the water disinfection process.

The announcement was made by Jeff Mosher, executive director of NWRI. “Because of its advantages,” said Mosher, “demand for UV is growing, based in part on the use of recycled water to meet water supply needs. The UV Guidelines are the most commonly used reference by regulators, water and wastewater agencies, design engineers, and equipment manufacturers to ensure the efficacy of UV installations.”

“We are excited to have this important announcement presented at the IUVA conference today,” said Deb Martinez, executive director of IUVA. “This exemplifies the leadership that IUVA provides in the development and implementation of ultraviolet technologies used in the treatment of water.”

The UV guidelines were originally prepared in 2000 by a team of water industry experts that included university researchers, state and federal regulators, and consultants from the U.S. and abroad.

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American Ultraviolet UV solutions reduce unwanted surface and airborne microbes in patient rooms, surgical suites, ICU’s and other areas pathogens may be present.

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Atlantium is **validated** and **proven** based on live 4-log Adenovirus challenges.

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No other system has full 4-log Adenovirus validation, or provides a better firewall than chlorine and ozone.

Thanks to Atlantium’s patented hydro-optic technology, medium pressure UV, two sensors per lamp and real-time monitoring & control.

- Already accredited and in use for full 4 log virus credit for the Ground Water Rule in Pennsylvania, New York and more
- Fully accredited for FDA Compliance for Pasteurized Equivalent Water
- Hydro-optic technology recycles photons; needs less energy and fewer lamps
- Atlantium Medium-Pressure UV prevents microbial repair, fights biofilms, effective in all water temperatures

The revisions in the third edition of the UV guidelines reflect experience gained from the application of the guidelines over the years. Specifically, the “Protocols” section of the guidelines was updated for the following purposes:

- To provide a standardized protocol for conducting “spot-check” performance MS-2 based viral biosays to validate the installed performance of full-scale UV disinfection systems.
- To standardize the assignment of UV dose when conducting MS-2 based viral assays by making use of a standard MS-2 dose-response relationship.

Key revisions include:

- All reclamation systems must undergo commissioning tests that demonstrate disinfection performance is consistent with design intent.
- Velocity profiles have been eliminated as an option for transferring pilot data to full-scale facility design.
- On-site MS-2 based viral assays are used for both the validation and commissioning test.
- A standard MS-2 dose-response curve is used to derive the reduction equivalent dose.
- The design equation is based on the lower 75-percent prediction interval for reclamation systems. The lower 90-percent prediction interval is used for drinking water systems.
- Commissioning tests will require seven out of eight on-site measurements exceeding the operational design equation.
- The addition of an appendix to illustrate the computations involved in the application and evaluation of UV disinfection systems.

The third edition of the UV Guidelines was revised by Robert W. Emerick, Ph.D., P.E., of Stantec Consulting Services and George Tchobanoglous, Ph.D., P.E., NAE, professor emeritus at the University of California, Davis. Dr. Emerick was responsible for the first permitted unfiltered drinking water UV disinfection facility in the U.S. and continues to regularly design and troubleshoot reclamation-based UV disinfection systems. Dr. Tchobanoglous has authored or coauthored over 350 publications on water and wastewater treatment and solid waste management, including 13 textbooks and five engineering reference books.

The UV Guidelines are available to download at www.nwri-usa.org/uvguidelines.htm.

HANOVIA’S PURELINE UV RANGE IDEAL FOR FOOD, BEVERAGE AND BREWING APPLICATIONS

Hanovia’s new PureLine UV range provides chemical-free treatment and water disinfection for the food, beverage and brewing sector.

Joining the PharmaLine and SwimLine ranges, the PureLine is the latest industry-specific UV system from Hanovia designed to make product selection as easy as possible. All that’s needed to choose the correct model is the application and the required flow – the appropriate model is then simply selected from the appropriate data-sheet. Hanovia will have already specified the necessary dose, chamber geometry, lamp type, surface finish, seal materials and connections that are typically required by that application. Special designs can also be supplied for users who have unusual requirements.

Standard PureLine models are available for the disinfection of water, syrups, brines and for the de-ozonation of process water (designated D, S, B and DO respectively), with the range being supplemented by the ‘PureLine PQ’.

Ensuring biosecurity of water systems, the Performance Qualified PureLine PQ is tested and approved by independent experts to the requirements of the USEPA UV Disinfection Guidance Manual (UVDGM). Benefiting from full flow bioassays conducted by independent engineers across a wide range of operating and water quality conditions, the PureLine PQ guarantees 99.999% disinfection at its maximum bioassayed dose.
Providing proven, constantly displayed and verified disinfection, PureLine PQ is equipped with a calibrated absolute intensity UV monitor and controller, which automatically corrects the dose calculation as UV transmittance varies, without requiring an external UV transmittance monitor. This provides the user with an accurate and instant measurement of the PQ’s disinfecting activity. In addition, because the monitor remains outside the water flow, it can be removed and inspected without interrupting the process, allowing on-site verification using a portable reference UV sensor traceable back to a NIST standard. In addition, material certificates for all the FDA compliant wetted parts and an ability to cope with CIP/SIP (Clean-In-Place/Sterilization-In-Places) provides compatibility with food and beverage requirements and above all ensures UV biosecurity of the highest level.

Operating at a lower energy level, PureLine D is intended for general purpose disinfection of water or CIP solutions as part of a multi-barrier system, while the PureLine S and B systems are designed specifically for the disinfection of sugar syrups, liquid sugars, de-aerated liquor (in breweries) and for disinfection of brine in the meat packaging industry.

The PureLine range utilizes either High Output Amalgam or Medium Pressure UV lamps, whichever is most effective for the application in question. Lamp changing is a simple procedure that can usually be done by on-site personnel with no specialist training. With lamp life up to 12,000 hours and with electronic ballasts and unlimited start-stop and variable output capability on some models, life-time costs and energy consumption are optimized across the range.

The entire range is rated to IP54 as a minimum, with options to IP65, and has a state-of-the-art controller with an on-board message display panel, as well as many other safety and alarm features.

The PureLine range therefore offers the food and beverage industry a suite of UV treatment products optimized to meet the needs of their applications. The systems are easy to install and maintain and provide non-chemical treatment with no possibility of unwanted bi-products or residues. Above all, it provides the peace of mind that comes with a guaranteed disinfection performance.

**RINGIER TECHNOLOGY INNOVATION AWARD**

UV disinfection specialist Hanovia has won the Ringier Technology Innovation Award for the Food and Beverage Industry (Disinfection Technology category) at a ceremony held recently in Shanghai, China. The Award was given for Hanovia’s new PureLine PQ UV system which provides chemical-free treatment and water disinfection for the food, beverage and brewing sector. Hanovia previously won the Award in 2010.

**WATER RESEARCH FOUNDATION LAUNCHES TWO AWARD PROGRAMS TO RECOGNIZE INFLUENTIAL RESEARCHERS AND SUBSCRIBING UTILITIES**

At its annual Subscriber Breakfast, the Water Research Foundation last June announced the inaugural winners of two new award programs.

The Research Innovation Award honors researchers and research teams who have made significant contributions to advancing the science of water through Foundation-sponsored research. The Outstanding Subscriber Award for Applied Research honors subscribing utilities that have made notable improvements to their treatment, delivery, and/or management processes through the successful application of Foundation research.

In announcing the awards and the 2012 winners, executive director Rob Renner said, “The Foundation relies on the dedication and passionate support from
researchers and our subscribing utilities to achieve our core mission of advancing the science of water. These two constituencies are instrumental to what we do and to providing safe drinking water to millions of individuals worldwide. It’s time that they received a standing ovation from the Foundation.”

This year’s Research Innovation Award was presented to Jennifer Clancy, Ph.D., of Tetra Tech, Inc. Dr. Clancy made the discovery that low levels of ultraviolet light (UV) inactivate Cryptosporidium in water. Prior to her discovery it was accepted and “proven” that these pathogens were resistant to UV. Cryptosporidium became widely recognized as a public health threat in the 1980s when thousands of people became ill as a result of outbreaks in Carrollton, Ga., Swindon and Oxford, England and, in 1993, in Milwaukee, Wis., where more than 100 people died. Dr. Clancy’s discovery led to major changes in drinking water regulations worldwide, and has provided significant improvement to public health protection from a parasite that is ubiquitous in the environment and difficult to control in treated drinking water supplies.

Two Outstanding Subscriber Awards for Applied Research were presented at this year’s event. The first went to American Water, which exhibited exemplary leadership in the development of important research as part of the investigation team on at least 14 Foundation projects during the last five years. Their leadership on issues such as distribution system pressure management, metering, back flow prevention, corrosion control, and microbial management has been particularly significant.

A second award was presented to the New York City Department of Environmental Protection (NYC DEP). Their leadership and participation in more than 35 Foundation projects during the last five years on a broad number of research topics has helped to ensure that the Foundation’s work is useful not only to the City of New York, but to the water community in general.

Award nominations are accepted from the Foundation’s Board of Trustees, staff, subscribers, researchers, and other partners. The Foundation’s Board of Trustees’ Awards Committee selects each year’s winners.
Neptune-Benson Acquires ETS

Neptune-Benson, LLC (Neptune-Benson), a leading manufacturer of commercial aquatic filtration systems, announced recently that it has acquired the business of Engineered Treatment Systems LLC (“ETS”), a leader in Ultraviolet (UV) Technology for aquatic, industrial and municipal applications. The ETS acquisition follows Neptune-Benson’s recent purchase of Lawson Aquatics, furthering progress towards the company’s strategic growth objectives.

Jon McClean, ETS President said, “The acquisition of ETS by Neptune-Benson is the next step in our company’s progression and allows us to further our investment in products, people and customers. This partnering provides ETS with expanded resources for R&D and technical expertise. ETS is now positioned for further growth through accelerated product development and a number of other exciting strategic initiatives that have been identified with Neptune-Benson. The management team at ETS will remain to best facilitate a seamless transition and go-forward operations of the company. We are very excited about the opportunities ahead.”

While the companies will look for further opportunities to share resources and build synergies, ETS will continue to operate out of their new headquarters facility in Beaver Dam, Wisconsin. The proven track record that both companies bring in assisting commercial aquatics installations to provide a safe and enjoyable experience for their patrons is unparalleled in the aquatics industry. ETS has successfully bridged their aquatics success into the industrial and municipal sectors and will utilize this expertise to help identify suitable applications for Neptune-Benson family products as well.

“ETS makes a perfect addition to our growing organization,” said Barry Gertz, Neptune-Benson CEO. “Their reputation within the world of aquatics is unsurpassed and the experience they bring in the industrial and municipal arenas opens up even more growth opportunities for our filtration systems. The combined capabilities of our organizations will further increase our ability to deliver quality products and services to our global customer base.”

Since 1956, Neptune-Benson has been a leading manufacturer of filtration systems for aquatic centers, waterparks and aquatic life support. Featuring the award-winning Defender® Regenerative Media Filter, Neptune-Benson also offers steel & fiberglass sand filter systems; the AEGIS anti-entrapment shield; fiberglass movable bulkheads; Dominion butterfly valves; Guardian strainers along with the complete family of Lawson Aquatics brand products. See: www.neptunebenson.com

Based in Beaver Dam, Wisconsin, Engineered Treatment Systems LLC is a leader in the development and manufacture of UV systems, specializing in closed vessel UV technology. The company’s world-class UV systems offer treatment solutions for a range of uses from recreational water to municipal and a wide variety of industrial applications. With advanced technology and a wealth of experience, ETS has the expertise to provide effective and cost efficient solutions for a broad range of industry needs. See: www.ets-uv.com.
BERSON EXHIBITING AT IWA WORLD WATER CONGRESS & EXHIBITION IN BUSAN, SOUTH KOREA

UV disinfection specialist Berson UV-techniek (www.bersonuv.com) will be represented at the Netherlands Pavilion at this year’s IWA World Water Congress and Exhibition in Busan, South Korea, Sept. 16-21. Organized by the International Water Association (IWA), the high-profile event attracts thousands of water professionals and organizations from across the globe.

“The IWA World Water Congress and Exhibition attracts some of the most influential figures in the global water industry,” comments Berson’s Managing Director Paul Buijs. “Over 5,000 delegates and 1,500 trade visitors are expected to attend the Busan event, and as we are leaders in the use of UV for water and wastewater treatment, we consider it important to be there. We believe that the unique combination of congress and trade fair makes IWA 2012 the ideal platform for us to present our UV technologies and latest research findings, particularly in the areas of water and wastewater reuse,” added Paul.

Berson’s booth will be located in the Netherlands Water Pavilion, which will also feature many of Holland’s other leading water companies. Holland is one of the nations most at risk from the environmental effects of climate change so, not surprisingly, it is also one of the most forward-thinking in terms of environmental technology.

Pilot Testing of the Latest Microwave UV Technology for a North Texas Municipality

A leader in innovative technologies, the Carollo Research Group performs independent third-party analysis of the latest UV systems for reuse, wastewater, and drinking water disinfection, including ultra-high intensity low-pressure lamps, medium-pressure reactors, sensor-based systems, and microwave UV systems. Along with detailed testing, Carollo provides our clients with groundbreaking solutions for maximum performance and cost savings. Contact us today, and together we can begin “Working Wonders With Water®”... with you.

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LIGHT INDIA 2012 RECEIVES STRONG SUPPORT FROM GLOBAL LIGHTING BRANDS

The 2012 edition of Light India, co-organized by Messe Frankfurt and the Electric Lamps & Components Manufacturers’ Association of India (ELCOMA), has received strong interest from the international community. The debut fair, which will be held from Oct. 5-8, 2012, at Pragati Maidan in New Delhi, India, is expecting 20,000 visitors and an exhibition space totaling 16,000 sqm.

Since the show’s announcement, interest from the international lighting industry has been high. The 2012 show has, so far, confirmed 120 exhibitors from China, India, Japan, Taiwan, Saudi Arabia, Singapore, the UAE and the U.S. Big-brand exhibitors currently include Philips, Osram, Bajaj, Surya Roshni, Crompton, Anchor by Panasonic, BAG Electronics, Wipro and Energetic Lighting. Majority of exhibitors intend to focus on energy efficient lighting and LED technology.

Mr Raj Manek, Managing Director of Messe Frankfurt Trade Fairs India Pvt. Ltd noted: “Light India continues to be the largest and most prestigious lighting exhibition in India. Showcasing the largest range of lighting products as well as hosting several live demonstrations, the show will bring together leading architects, consultants and government policy makers in large numbers. We believe that by focusing on green lighting and electronic systems, we’ll be able to attract phenomenal interest from important sectors including infrastructure, residential and commercial property development as well as manufacturing.”

With the support of international associations such as the Global Lighting Association, Asia Lighting Compact, United Nations Environment Programme (UNEP) and the Department of Heritage and Environment, Light India will host two days of technical seminars and concurrent events, focusing on emerging technologies and their application. Some of the world’s leading ex-

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Experts and business leaders will deliver papers on the industry’s latest developments. Recommendations made by experts during the seminar will then form White Papers which will be submitted to the government for decision making and future policy guidelines.

In order to encourage the growth of LED lighting design among students and architects, Light India will host the LED Lighting Best Design Awards with the support of the Indian Institute of Design and Council of Architecture. A gala dinner will also be organized with special performances that present innovative uses of lighting. Coinciding with Light India, the week from 4 – 8 October 2012 has been deemed the National Energy Efficient Week in India.

To find out more about the 2012 edition of Light India, please visit www.light-india.in or email info@india.messefrankfurt.com.

GUANGZHOU INTERNATIONAL LIGHTING EXHIBITION: LARGEST EVER EXHIBITOR AND VISITOR ATTENDANCE IN SHOW’S HISTORY

The Guangzhou International Lighting Exhibition, Asia’s most influential and comprehensive lighting and LED event, which was held June 9-12, 2012, at the China Import and Export Fair Complex in Guangzhou, set new records for exhibitor and visitor attendance.

The 17th edition of the show attracted 2,914 exhibitors showcasing their products in 21 halls covering 210,000 sqm. There were 110,406 visitors from 111 countries and regions. Exhibitor numbers also rose to 2,931, an increase of 41 per cent compared with last year and the total exhibition area was 210,000 sqm, covering 20 halls.

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Mr Richard Li, Deputy General Manager of Messe Frankfurt in China said that the Guangzhou International Lighting Exhibition is now firmly established as Asia Pacific’s major sourcing, networking and knowledge hub for the LED industry. “This year’s record figures leave no doubt that the show has become the number one event for exhibitors and visitors wanting to gain a comprehensive global overview of what’s happening in the fast moving LED industry,” Mr Li said. “Supporting the show’s reputation is the fact that our exhibitors are major domestic and international players in the increasingly competitive LED market.

REGISTRATION OPEN FOR 2012 NWRI CLARKE PRIZE CONFERENCE

Registration is now open for the 2012 NWRI Clarke Prize Conference, which will be held on Friday, November 2, 2012, at the Hyatt Regency Newport Beach in Southern California. The one-day conference will focus on “Research and Innovations in Urban Water Sustainability.”

The purpose of the conference is to emphasize the newest research by NWRI’s Clarke Prize recipients – all groundbreaking pioneers and esteemed leaders in the water industry – and to showcase innovative water and wastewater agency projects that focus on water sustainability.

The crowning event of the conference will be the Clarke Prize Award Ceremony and Lecture, where bioremediation expert Pedro Alvarez of Rice University will be honored with the 2012 Clarke Prize for excellence in water research. The prize consists of $50,000 and a medallion. He will be the 19th Clarke Prize recipient.

Water and wastewater agency staff, academics, students, consultants, and local and state government representatives are encouraged to register for the conference at www.regonline.com/Clarke2012. The early registration deadline is October 9, 2012. The 2012 Clarke Prize Conference program will include over 12 presentations and four panel sessions. Topic areas include: Sustainability through Wastewater, Water and Energy, New Water Sources and Urban Water Sustainability. Presentations will be provided by several of NWRI’s Clarke Laureates, as well as by representatives from water and wastewater agencies.

The highlight of the program will be the Clarke Lecture given by Pedro Alvarez during the award ceremony. The Lecture will be on “Convergence of Nanotechnology and Microbiology: Emerging Opportunities for Water Disinfection, Microbial Control, and Integrated Urban Water Management.”

The conference is being sponsored by NWRI’s water and wastewater member agencies, as well as by NWRI corporate associates. Sponsorship opportunities are available. For more information, visit http://www.regonline.com/builder/site/tab3.aspx?EventID=1131383 or contact Jeff Mosher of NWRI at jmosher@nwri-usa.org for more details.

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Early Adoption of UV-C Light Emitting Diode Technology for Water Disinfection

Paolo Batoni,1 Jennifer G. Pagan,1 T. Robert Harris,1 Oliver Lawal,2 Karl G. Linden,3 Christina Bartow,3 and Sara Beck.3

1Dot Metrics Technologies, 9201 University City Blvd. Grigg Hall 258, Charlotte, NC 28223, USA
2Aquionics Inc., 21 Kenton Lands Road, Erlanger, KY 41018, USA
3University of Colorado at Boulder, 1111 Engineering, ECOT 441, Boulder, CO 80309, USA

ABSTRACT

UV-C light emitting diodes (LEDs) emit invisible radiation with wavelengths ranging from 200 nm to 300 nm; hence, they are suitable for germicidal applications. Commercial assimilation of UV-C LEDs for water disinfection has long been thought to be unfeasible mostly because of the relative immaturity of these devices. Though UV-C LEDs are still early in their development cycle, their application for water disinfection is very effective when integrated with a novel and very efficient reactor design. Development of such a system requires an integration of hydrodynamics, optics, thermal management, and electronics. This paper reports the multi-physics co-design of such a system.

Keywords: UV-C; LEDs; Light Emitting Diodes; Water Disinfection; Energy Efficiency; Germicidal.

Commercially available, individual UV-C LED chips typically provide less than 3 mW of optical power, however multi-chip packages can be assembled used to increase the optical output power to value > 120 mW.
UV-C LEDs can be packaged in a variety of configurations, including watertight hermetic, with packages having a diameter ranging 5 mm to 5 cm. A typical UV-C LED operates with a rapid (< 1 s with ordinary electronic drivers) power-on time at around 6 V and 20 mA. These efficiencies make UV-C LEDs ideal candidates for battery or solar powered applications. Table I illustrates a comparison of UV-C LED and Hg technology.

Table I. Comparison of UV-C and Hg Technology (Low Flow Rate - Low Volume)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Conventional Mercury Lamp</th>
<th>UV-C LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>&lt; 2 gpm/Watt</td>
<td>&gt; 20 gpm/Watt*</td>
</tr>
<tr>
<td>Mercury Content</td>
<td>20 – 200 mg</td>
<td>None</td>
</tr>
<tr>
<td>Warm up Time</td>
<td>2 – 15 minutes</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>Zero Flow Limit</td>
<td>10 – 60 minutes</td>
<td>No limit</td>
</tr>
<tr>
<td>Architecture</td>
<td>Cylindrical tube</td>
<td>Versatile</td>
</tr>
<tr>
<td>Voltage Current</td>
<td>110 – 240 V AC 0.5 – 2.0 A</td>
<td>6 – 12 V DC 0.02 – 0.2 A</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>14 – 230 W</td>
<td>0.1 – 10 W</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>&lt; 100 gpm</td>
<td>Currently &lt; 5 gpm</td>
</tr>
</tbody>
</table>

*As measured in the UV Pearl™ system for RED.

This paper presents recent breakthroughs and current initiatives that can advance the industrial adoption of UV-C LED water disinfection systems. Dot Metrics has developed a proprietary technology that compensates for the low optical power output of UV-C LEDs, while leveraging their strengths to allow an early assimilation of UV-C LEDs into new markets. In addition, Dot Metrics has introduced the use of a novel modeling technique in conjunction with the co-design of a proprietary, optically optimized reactor chamber that homogenizes photon flux and ensures liquid quasi plug-flow. The design also incorporates real time water transmittance and absorption sensing for intelligent operational control of the system. As a result, maximized particle residence time and optimized photon flux resulted in a revolutionary, very efficient water disinfection system.

Development of UV-C LEDs is expected to take a similar track to that of blue and red LEDs, and their efficiency is expected to surmount the wall plug efficiency of Hg lamps in the coming years. The wall plug efficiency (WPE) of LEDs (including UV-C LEDs), which is defined as the optical power output divided by the electrical input power, is ever-increasing. Currently, the best demonstrated WPE of UV-C LED is 8% (2) with increasing efficiencies expected as semiconductor material control issues are resolved, and novel light extraction techniques are introduced and refined. Red LEDs came onto the market in the mid 1970’s and incrementally increased efficiency until the mid-1980s when their development accelerated through both manufacturing and materials innovations. The result is that red LEDs currently have a WPE of over 80%. Blue LEDs were
affected by semiconductor material constraints that many considered insurmountable, however these fundamental challenges were resolved by Nakamura in the early 1990’s, and blue LEDs currently feature WPE’s of over 80% (3,4). Near UV LEDs, which are affected by semiconductor material constraints and light extraction challenges similar to that of UV-C LEDs, have recently reached a WPE of over 35% (5).

THERMAL DESIGN OF A COOLED SOLID STATE UV-C LED SOURCE

Recently, experimental UV-C LEDs have demonstrated > 10% (2) external quantum efficiency (EQE); nonetheless, currently available commercial UV-C LEDs exhibit single digit external quantum efficiencies and therefore readily produce excess heat, which must be removed. Currently their external quantum efficiency (EQE) is below 4%; hence, their optical power output is limited because >90% of the input electrical power is converted into heat (phonons), not photons. The EQE range of UV-C LEDs—as reported in the literature—is presented in Figure 3.

Proper thermal management of optical semiconductor devices improves performance and lifetime (6, 7). This is particularly important for UV-C LEDs. Optical output intensity and device lifetime can be particularly improved for those UV-C LEDs whose heterostructure is fabricated with a solid state, crystalline ternary alloy of aluminum, gallium, and nitrogen (AlGaN) which is typically affected by deleterious high defect densities. Non-cooled UV-C LEDs will quickly rise to high temperatures triggering self-deterioration and causing premature device failure. Packaged UV-C LEDs that are coupled to an improper thermal management system (i.e. an inadequate heat-sink) are provided with minimal heat exchange while still being subjected to high thermal stress; this is true even when operation takes place in low ambient temperature environments. The overall performance enhancement of UV-C LEDs subject to proper thermal management is illustrated in Figure 4.

The use of active heat exchangers is certainly beneficial to this application. Thermoelectric coolers (TECs), which are solid state semiconductor electric heat pumps, are devices that can be employed as the core of
a thermal management system. Nonetheless, the use of TECs requires dynamic thermal, electrical, and aging considerations. UV-C LED die sizes are currently restricted to a few hundred square microns mostly due to poor AlGaN quality (3). The extrinsic property of thermal capacitance, measured in J (kg · K)-1, is therefore low for each die. When the thermal turn-on transient of UV-C LEDs is considered, it will rise sharply due to the high current density in the UV-C LED and the low RC time constant of the thermal properties of AlGaN. Due to these factors, the momentary thermal transient can exhibit intensities more than ten times the average operating temperature of the semiconductor device. Sharp thermal transients occur in micron-scale masses (8), thus high transient heating is highly localized. For multi-chip packaged UV-C LEDs the heat conducted to neighboring dice will be subjected to power blurring due to heat diffusion in all dimensions.

OPTICAL DESIGN OF AN EFFICIENT UV-C LED REACTOR CHAMBER

The electrical efficiency of an UV-C fluid irradiation system will benefit from an efficient use of the UV-C photons emitted from the sources. Similarly, the cost of the system will be abated by decreasing the need for more or higher intensity UV-C sources.

FLUID DYNAMIC DESIGN OF AN EFFICIENT UV-C LED REACTOR CHAMBER

The inactivation rate of a UV-C LED reactor will be highly dependent upon the particle residence time within the reactor chamber. By means of Computational Fluid Dynamics (CFD) studies, Dot Metrics implemented, and developed a novel reactor design, which allows quasi-plug flow rates ranging from 0.1 gpm to above 2.5 gpm, and integrates a prototype of Dot Metrics’ UVinaire™. Fluid flow in Dot Metrics’ reactor designs was modeled using a combination of Fluent and Star CCM computational fluid dynamics modeling systems. Particles, which simulated pathogenic microorganisms, were released into the reactor chamber and tracked through the system under various fluid flow rates. Histograms of particle residence times in the reactor were generated from the models and were used to predict experimental performance of the reactor. The average particle residence time is described as the volume of the reactor, $V$, divided by the flow rate of the fluid, $Q$. An ideal particle residence time histogram would consist of a delta function centered on $V/Q$. Even small fractions of particles escaping early from the reactor will limit the achievable log inactivation. An early-stage prototype, which was modeled, and then tested experimentally, prematurely released a large percentage of particles, which limited the performance of the reactor to an approximated 2 log reduction value of E. coli bacteria at a flow rate of 0.2 gpm shown in Figure 5 (right). A battery of several prototypes were modeled, manufactured and tested during development including an improved prototype design which has the particle residence time histogram given in Figure 5 (left). Note also the distribution of the histogram around $V/Q$, which is a quick method of predicting performance of the model.

Actual log reduction in the reactor was predicted in the following manner: each particle has an associated resi-

![Figure 5: Particle residency results for extreme variations in reactor design including volume, inlet, and outlet dimensions.](image)
idence time, or time spent being irradiated in the reactor. These particles were binned to time bins of a tenth of a second, as shown in Figure 5 (right). A single stage decay model of Chick's law, Eq. 1 was applied to each of the bins to determine the survival fraction of the particles in that bin.

\[ S = e^{-kD} \quad \text{Eq. [1]} \]

The UV rate constant, \( k \), and irradiance, \( D \), were experimentally determined. The predicted log reduction of the system was determined as the log of the ratio of the sum of the surviving particles and the initial number of particles.

**BIOLOGICAL ASSAY**

The desired product of an effective UV water treatment system is an efficient inactivation rate measure by flow rate and log reduction of viable bacterial colonies. The UVinaire™ monolithic UV-C fixture integrates UV-C LEDs, electronics, sensing, and the thermal management system as described above. The UVinaire™ delivers an engineered flux of photons with an application dependent peak emission wavelength ranging 265 to 280 nm. A beta-prototype of the above design was used to conduct a systematic series of bioassays with E. coli surrogates MS2 and T1. Test results indicate 6-log Reduction for the T1 phage at flow rates up to 2 gpm.

Studies to determine wavelength calibrated UV doses for bacteriophages T1 and MS2, and their UV Rate Constants in an optically engineered 3-D UV-flux environment were completed. Experimental results indicated that UV doses delivered by UV-C LEDs with peak emission ranging 265 to 280 nm enables an enhanced log reduction capability with respect to 254 nm UV doses delivered by LP lamps. These tests confirmed that the reactor optical design allows a 24X enhancement over Hg-based lamps in the susceptibility of microorganisms to UV.

**ACKNOWLEDGMENTS**

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**REFERENCES**


Combined Life Cycle Assessment and Life Cycle Costing of UV-based Treatment of Emerging Contaminants

Ekaterina Rokhina, Tony Singh, Marianne Curran, Rominder Suri

Water and Environmental Technology (WET) Center
Civil and Environmental Engineering Department
Temple University, Philadelphia PA 19122
Corresponding author’s E-mail: rominder.suri@temple.edu

ABSTRACT
UV-based methods were studied for the removal of mixture of steroid hormones (17α-estradiol, 17β-estradiol, 17α-dihydroequilin, 17α-ethinyl estradiol, estriol, estrone, equilin, norgestrel, gestodene, trimethoestrone, medrogestone and progesterone) in aqueous solution. Contribution and comparative life cycle assessment (LCA) study was applied to assist the decision making for the selection of the optimal treatment method from technological and environmental point of view. The results showed that chemically-assisted UV processes (e.g. UV/hydrogen peroxide, UV/persulfate) enhance not only degradation efficiency of these contaminants, but are more beneficial from environmental and economical point of view. Qualitative assessment was provided by eco-efficiency index (EEI). The most eco-efficient option was UV/persulfate, which had the lowest EEI (0.55), whereas the EEI for UV/hydrogen peroxide was 0.61.

Keywords: UV-photolysis, UV/hydrogen peroxide, UV/persulfate, steroid hormones, Life Cycle Assessment

INTRODUCTION
Over past two decades photochemical technologies have become more attractive than conventional methods due to several reasons. It is simple and clean technology, cost-effective in many applications, which provide not only treatment of many organic contaminants but also disinfection (1). Ultraviolet (UV) based technologies belong to the class of advanced oxidation processes (AOP), which are primarily based on the generation of hydroxyl radicals (•OH), having an oxidation potential of 2.7 V. Hydroxyl radicals are formed through direct photolysis of hydrogen peroxide (H₂O₂) or photo-induced processes such as photo-Fenton type reactions or photocatalysis. The persulfate anion (S₂O₈²⁻, E₀ = 2.01 V) is another strong oxidant that can be activated to generate an even stronger oxidant known as a sulfate radical (SO₄²⁻•, E₀ = 2.4 V). The UV direct photolysis is restricted to those pollutants that exhibit large molar absorption coefficient and quantum yields, whereas the addition of photocatalyst or hydrogen peroxide makes the process to be less sensitive to the nature of treated compound (2). Continued advances of technology include (i) high efficiency for removal of wide range of compounds (due to unselectivity of •OH), (ii) simple reactor design, (iii) easy exploitation (3). The selection of UV system depends on the cost of equipment, operation and maintenance, which in turn, is affected by water quality, system design, and operation parameters (design flow rate, reagents doses, reaction pH, etc.).
The use of complex advanced technologies to remediation of persistent contaminants may pose risk to the environment and human health due to increased greenhouse gas emissions, higher demands for energy and releases of pollutants to the environment. Therefore, an optimization analysis must be performed to estimate the environmental impacts of the treatment technology, while the toxicological risks associated with contaminants are reduced. In this context, the LCA methodology can provide a holistic approach for environmental assessment, in which environmental and health impacts in different places and at different moments in time are taken into account (4). LCA could be used as a method to define and reduce the environmental burdens from a technological process by identifying and quantifying energy and materials usage, as well as waste emissions, assessing the impacts of these wastes on the environment and evaluating opportunities for environmental improvements over the whole life cycle (5). Because of its holistic approach, LCA is becoming an increasingly important decision-making tool in environmental management. Life Cycle Costing (LCC) is used to optimise the cost of acquiring, owning and operating of technology during its life. The methodology is similar to LCA and aims to identify and quantify all the significant costs involved in that life, using the present value technique (6). Therefore, the combination of LCA and LCC will ensure the adoption of the optimum technology.

The current study describes the technological aspects of the UV-based removal (UV-photolysis, UV/hydrogen peroxide and UV/persulfate) of steroid hormones mixture: 17α-estradiol (17α, 17β-estradiol (E2), 17α-dihydroequilin, 17α-ethinyl estradiol (EE2), estradiol (E3), estrone (E1), equilin, norgestrel, gestodene, trimegestrone, medrogestone and progesterone. All three technologies were assessed by combined LCA and LCC to provide a comprehensive overview and to assist the decision making for the selection of the optimal treatment method.

**MATERIALS AND METHODS**

**Chemicals and reagents**

The following steroid hormones (minimal purity) were obtained from Sigma Aldrich or Sterloids, Inc.: 17α-estradiol (98%), 17β-estradiol (97.1%), 17α-dihydroequilin (99.4%), 17α-ethinylestradiol (99.1%), estrone (100%), estriol (100%), equilin (99.9%), gestodene, progesterone (99.1%), norgestrel (99.1%), and 3-O methyl estrone (internal standard, 98%). Methanol (HPLC grade), toluene (HPLC grade), and amber glass bottles were obtained from Fisher Scientific. Varian Bond Elut 3mL/500mg C-18 solid phase extraction (SPE) adsorbent cartridges were obtained from Varian Inc.

**Steroid hormones treatability study**

UV photolysis experiments were conducted to test the effect of retention time on steroid hormones degradation. Experiments were conducted at retention times of 20 and 10 minutes, corresponding to flow rates of 200 and 100 mL min⁻¹, respectively. Different oxidizing agents (hydrogen peroxide and persulfate) were tested at various concentrations, with a retention time of 10 minutes. The concentrations of the oxidizing agents were 5 and 10 mg L⁻¹ for H₂O₂, and 2, 5, and 10 mg L⁻¹ for persulfate. For both UV/H₂O₂ and UV/persulfate experiments, H₂O₂ and persulfate were added to the working solution prior to UV exposure. The lamp intensity for these experiments was 7.9 mW cm⁻².

The stock solution of hormones (100 mg L⁻¹) was prepared in methanol and stored in silanized amber glass volumetric flask at 4°C. Aqueous working solutions of steroid hormones (25 µg L⁻¹) were prepared by the addition of 1.25 mL of stock solution to 5 L deionized water. 250 mL samples were extracted using SPE and then analyzed using GC/MS/MS.

**Analysis of steroid hormones with SPE Gas Chromatography (GC) – tandem Mass Spectrometry (MS)**

SPE was carried out using Varian Bond Elute C-18 SPE cartridges, which were initially activated using 3mL of methanol and rinsed with 3 mL of DI water. Samples were passed through SPE cartridges at a flow rate of 5 mL min⁻¹. The cartridges were then rinsed twice with 3mL of DI water and eluted with 6mL of methanol. The eluent was collected in a clean, silanized test-tube and 1mL of internal standard was added. The eluent was then dried in a Genevac centrifugal evaporator at 40°C and 12mbar vacuum.

After drying, the samples were derivatized by the addition of 25µL of pyridine and 25µL of bis(trimethylsilyl) trifluoro-acetamide (BSTFA). After addition of pyridine and BSTFA, the sample was left to stand for 15 minutes at 26°C to enable sufficient reaction time. 250µL of toluene was then added, and the sample was vortexed. The sample was transferred into a 0.25mL silanized GC glass insert and was analyzed on GC/MS/MS.
GC/MS/MS analysis was performed using a Waters Quattro micro. Auto injections were made using split mode with a split ratio of 0.1, and an injection volume of 1.0 µL. Injection temperature was 250°C. The initial temperature of the oven was 110°C. The temperature was ramped to 250°C at a rate of 20.0°C min⁻¹, and held for 8.0 minutes, then ramped to 265°C at a rate of 1.0°C min⁻¹, and finally ramped to 300°C at a rate of 7°C min⁻¹ and held for 34 minutes. Transfer line to the MS was maintained at 300°C and the electron energy was 70eV (7).

LCA METHODOLOGY

Goal and scope definition
The goal of the study is to apply streamlined LCA to assess the UV-based treatment technologies (UV-photoysis, UV/hydrogen peroxide and UV/persulfate) for removal of mixture of steroid hormones. This assessment will highlight the critical sources of environmental impact in the process life cycle, and the areas where improvements should be made when implementing these techniques to a full scale. Therefore, primary goal of the current study is to assess the operation of aforementioned technologies for the removal of hormones. The secondary goal is to combine the obtained results with streamlined life cycle costing (LCC) study and to provide the comparative analysis according to the results.

The term “streamlined”, used in the LCA context refers to “simplified”. The border between detailed and streamlined LCA is not straightforward. However, the streamlined approach in LCA allows to perform LCA that reduce the scope, cost, and effort required for studies that use an LCA framework. The current study provides a streamlined LCA used for purposes of technology performance evaluation, which subsequent determining whether an additional study is needed and where that study should focus.

The main characteristics making this study a streamlined LCA are the following:
• Some life cycle stages are left out, both upstream and downstream of the AOP.
• Uses the most readily available data. This is considered the key streamlining method in this particular study, referring to the fact that laboratory data is used as the basis for the inventory phase. In the case of the emerging technologies for the removal of ECs the bench-scale data is the most readily available to assess a chemical process, and this constitutes an advantage, but also an inconvenient: the advantage is that potential impacts and possibilities for improvement can be detected at the beginning of the R&D stage; on the other hand, the main inconvenient is that data is incomplete (this links with the first point) and represents the furthest situation for the process from being optimized.

Functional unit and system boundaries
The function of the system has been defined in a wide sense as: “Degradation of the steroid hormones from 1m³ of water.” System boundaries are presented in Figure 1 as general flow diagram. In this section, all processes (both included and excluded) considered in the study are identified, as well as the reasons for their inclusion or exclusion.

Excluded processes:
1. Infrastructure and equipment for the different treatments are not included in the LCA. Infrastructure and equipment used in the laboratory is not considered to be representative. Moreover, the current study focuses on the comparative study of the performance of three UV-based technologies, which

![Figure 1. System boundaries](image-url)
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will have relatively the same infrastructure.

2. Any pre-treatment or post-treatment stages. The study focuses in AOPs, the functional unit has been defined in such a way that processes placed before and after the AOP can be excluded, as they are constant for all treatments.

3. CO₂ emissions produced by the mineralization of steroid hormones

**Included processes:**

1. Production of electricity consumed by the treatment technologies. This sub-system comprises extraction of resources, transport, and electricity production, as well as production of the capital equipment required for these operations.

2. Production of UV lamp, hydrogen peroxide and persulfate. This sub-system comprises extraction of resources, transport, packaging, production stage, transport to the wastewater treatment plant, and also production of capital goods.

**Inventory analysis**

The inventory analysis is a technical process of collecting data, in order to quantify the inputs and outputs of the system, as defined in the scope (8). Energy and raw materials consumed, emissions to air, water, soil, and solid waste produced by the system are calculated for the entire life cycle of the product or service.

The present study includes two types of data: the first-order corresponds to the data used to calculate the inputs from technosphere to the foreground system, and the second-order data corresponds to the data used to account for the environmental interventions related to those inputs from the background system. The main hypothesis and assumptions in the inventory phase of the LCA can be summarized as follows:

1. Infrastructure and equipment for the different treatments are not included in the LCA. Infrastructure and equipment used in the laboratory is not considered to be representative.

2. The energy used to run the US, UV, ozonator and pumps have been assumed to be electricity delivered from the US grid (medium voltage + IMPORT).

3. Hydrogen peroxide and persulfate are totally consumed during the reaction.

4. UV lamp was included in the group of consumables and therefore, its life cycle was fully assessed. The end-of-life management concept is taken from the Guide for Waste managers, dealing with mercury lamp recycling (http://www.swana.org/extra/lamp/1ropmanualfinal.pdf)

**IMPACT CATEGORIES AND IMPACT ASSESSMENT METHOD**

The method, used for the environmental impacts assessment is IMPACT 2002+. The IMPACT 2002+ methodology combines two approaches: the classical

<table>
<thead>
<tr>
<th>Topic</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (Eastern US grid)</td>
<td>Representative of year 2000 mix of fuels used for utility electricity generation in the Eastern U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources (US LCI, 2008).</td>
</tr>
<tr>
<td>Electricity consumption by the AOP technology and auxiliary equipment (e.g. pumps)</td>
<td>Data from laboratory experiments and equipment power</td>
</tr>
<tr>
<td>Hydrogen peroxide, H₂O₂ (30%)</td>
<td>Data from Ecoinvent, calculated using the methodology from ETH (2003). Total aggregated inventory.</td>
</tr>
<tr>
<td>Sodium persulfate, Na₂S₂O₈</td>
<td></td>
</tr>
<tr>
<td>Chemical products consumption by the AOP</td>
<td>Data from laboratory experiments</td>
</tr>
<tr>
<td>UV Lamp</td>
<td>Data from the manufacturer</td>
</tr>
<tr>
<td>Process water for cooling and washing</td>
<td>Raw materials (007732-18-5)</td>
</tr>
<tr>
<td>Ozone production</td>
<td>Total requirements per g ozone produced: 0.09 kWh</td>
</tr>
<tr>
<td>Transport distances</td>
<td>Assumptions</td>
</tr>
<tr>
<td>Packaging</td>
<td>Data from US LCI database calculated using the methodology from Franklin associates (2008).</td>
</tr>
</tbody>
</table>
assessment methods, which restrict quantitative modeling to relatively early stages in the cause-effect chain to limit uncertainties and classify and characterize LCI results in so-called midpoint categories and damage oriented methods, which model the cause-effect chain up to the damage, sometimes with high uncertainties.

The midpoint impact categories provided by the method are: Carcinogens, Non-carcinogens, Respiratory inorganics, Ionizing radiation, Ozone layer depletion, Respiratory Organics (RO), Aquatic Ecotoxicity (AE), Terrestrial Ecotoxicity (TE), Terrestrial Acid/nutria (TA), Land Occupation (LO), Aquatic Acidification (AA), Aquatic Eutrophication (AEU), Global Warming (GW), Non-renewable Energy (NE), and Mineral Extraction (ME). These midpoint categories form the following end (damage) categories, which represent quality change to the environment: Human Health (HH), Ecosystem Quality (EQ), Climate Change (CC) and Resources (R).

RESULTS AND DISCUSSION
Degradation of steroid hormones
Two groups of steroid hormones were studied: (i) estrogens: 17α- and β-estradiols, estrone, estriol, equilin, 17α-dihydroequilin, 17α-etinylestradiol, and (ii) progestins: trimegestone, progesterone, norgestrel, gestodene and medrogestone. Treatability experiments for all aforementioned steroid hormones were conducted in mixture by three UV-based technologies: UV photolysis, UV/hydrogen peroxide and UV/persulfate.

UV photolysis
Previous studies on the photolysis of estrone and 17β-estradiol in aqueous solutions concluded that UVC (200-280nm) radiation was found to be much more effective than UVA–vis (315-700 nm) (9). However, steroid hormones have a UV absorption minima at approximately 250 nm, and therefore, the degradation of these compounds by exposure to low-pressure UV lamps (254 nm) is expected to be low (10).

UV photolysis experiments were performed at flow rates of 100 mL min
-1 and 200 mL min
-1. Figure 2 shows the removal efficiencies for all hormones. The highest removal efficiencies (80-98%) were achieved for estrone, equilin, gestodene, and medrogestone. Low degradation efficiency of approximately 40% to 50% was observed for 17 α- and β-estradiols, estriol, 17α-etinylestradiol, 17α-dihydroequilin and trimedgestrione. The increase of retention time did not lead to enhancement of degradation process. Overall, UV photolysis treatment was not very effective for mixture of steroid hormones. Despite the structural similarities, the behavior of these compounds differs. For example, estrone is photolysed at faster rate than 17 β-estradiol which is in accordance with previous studies (11). The progestins in general demonstrate better ability to be photolysed than estrogens. This difference can be explained by reported quantum yields of these compounds as 220x10
-2 of progesterone and 4–5 x10
-2 mol Einstein
-1 of estrogens (E2 and EE2) (9). In general, the photolytic degradation follows pseudo first-order rate order for all the compounds. It was suggested that the photolysis of E1 and E2 causes the rupture and oxidation of the benzene ring to produce compounds containing carbonyl groups (11).
Effect of $\text{H}_2\text{O}_2$ as an oxidizing agent

The enhancement of the UV-photolysis can be achieved via production of $\cdot\text{OH}$ radicals. In such hybrid technologies the efficiency of the oxidation process strongly depends on experimental conditions (12). For practical application an understanding of the photo-degradation mechanism is very important to achieve improvements in the yield and the efficiency of these processes. Figure 3 shows the impact of the hydrogen peroxide concentration on the removal efficiency of steroid hormones mixture. Addition of $\text{H}_2\text{O}_2$ significantly increased the removal efficiencies for all steroid hormones in comparison with UV-photolysis. With the addition of 5 mg L$^{-1}$ (142 mM) of hydrogen peroxide, the observed hormones removal was more than 90% for nine of the steroid hormones. Further increase of the dose up to 10 mg L$^{-1}$ (284 mM) lead to the enhanced removal for almost all steroid hormones up to 95%. Similar observations were also made by (10, 13), who found that the addition of peroxide removed up to 90% of both 17$\beta$-estradiol and 17$\alpha$-ethinyl estradiol, which was a significant increase in comparison to UV photolysis. However, with subsequent increase in the dosage of hydrogen peroxide from 142 mM to 284 mM the removal efficiency of trimegestone slightly decreased.

Effect of persulfate as an oxidizing agent

Similar to hydroxyl radicals, sulfate anion radicals may react with wide range of organic compounds (14). It is a strong oxidant with comparable reactivity to hydroxyl radical (oxidation potential 2.4 and 2.7 V, respectively). Sulfate radical anion itself could be generated by the scission of the peroxide bond of persulfate. In previous studies, the persulfate degradation has been performed by photolysis at wavelengths from 248 to 351 nm (15). The photolysis of $\text{S}_2\text{O}_8^{2-}$ has been postulated to result in the formation of two $\text{SO}_4^{2-}$ radicals:

$$\text{S}_2\text{O}_8^{2-} + \text{hv} \rightarrow 2\cdot\text{SO}_4^{2-}$$

Moreover, sulfate radical anion can react with water to form hydroxyl radicals:

$$\cdot\text{SO}_4^{2-} + \text{H}_2\text{O} \rightarrow \cdot\text{OH} + \text{SO}_4^{2-} + \text{H}^+$$

The optimization of applied persulfate doses of 2-10 mg L$^{-1}$ (8-42 mM) is shown in Figure 4. The average removal of steroid hormones was 89, 92 and 95%, respectively. It was observed that an increase in persulfate concentration results in a higher removal for most of the steroids compounds, as can be seen in Figure 4. With 5 mg L$^{-1}$ (21 mM) of persulfate, removal efficiency reached above 90% for ten of the twelve hormones, however with double of the initial persulfate dose up to 10 mg L$^{-1}$ (42 mM) removal reached above 95% for ten of the hormones, nine of which reached above 98% removal. Interestingly, the increase in the dose of persulfate lead to a slight decrease of the removal of trimegestone, which is consistent with its behavior during UV/H$_2$O$_2$ treatment.

**Figure 4. Effect of persulfate concentration on the removal efficiency of steroid hormones by UV/persulfate (254 nm, lamp intensity 7.9 mW cm$^{-2}$, room temperature, circum neutral pH, retention time 10 min.)**

LIFE CYCLE ASSESSMENT

The two types of LCA studies performed were: contribution and comparative LCA. This approach is aimed not only to compare the different treatments, but also to identify the critical subsystems for each treatment and impact category. For this purpose the characterization results are used, disaggregating them so that the contribution of the chemical products, electricity and transports can be analyzed.

**Contribution analysis**

The contribution analysis shows the environmental impacts of each component of the system. This analysis is universal regardless the functional unit as it gives the general idea on the contribution of various subsystems to the general system. Figure 5 (a, b and c) shows these relative contributions for each treatment (UV, UV/hydrogen peroxide, UV/persulfate, respectively). Every impact indicator is expressed as 100%, being the contribution of a sub-system a fraction of this figure.
Figure 5. Contribution of subsystems in the characterization results for (a) UV, (b) UV/hydrogen peroxide, (c) UV/persulfate. The impact categories abbreviations: Carcinogens (C), Non-carcinogens (NC), Respiratory inorganics (RI), Terrestrial ecotoxicity (TE), Global warming (GW), Non-renewable energy (NE) and Mineral extraction (ME).
The impact categories affected by the UV-based treatment were: Carcinogens (C), Non-carcinogens (NC), Respiratory inorganics (RI), Terrestrial ecotoxicity (TE), Global warming (GW), Non-renewable energy (NE) and Mineral extraction (ME) (Figure 5).

From Figure 5 it is seen that electricity production is by far the most critical sub-system, accounting for at least 75% of the contribution to all impact categories in all treatments. In some cases electricity is responsible of almost 100% of the contribution. This noticeable impact is caused by the energy intensity of the AOPs and the characteristics of the Eastern US grid for electricity production, which relies to a considerable extent on fossil fuels, coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources.

The contribution of chemical reagents (e.g. hydrogen peroxide and persulfate) as well as production of UV lamp is low, only up to 10% for all the technologies. Transporting the chemicals to the wastewater plant implies a relatively low impact in comparison to the contribution of other components of the studied systems (e.g. electricity production).

In a summary, it can be stated that the AOPs are mainly energy-intensive, which means that the environmental impact is proportional to the overall energy consumption for each treatment.

**Comparative analysis**

In this section the different treatments are compared under the baseline scenario conditions. Figure 6 shows environmental performance for all the systems as single scores (Pt). The relative pattern in the other impact categories is very similar.

The single scores for all UV-based technologies were small due to small functional unit, however, the streamlined assessment revealed that all of the processes contribute in the following categories: Carcinogens (C), Non-carcinogens (NC), Respiratory inorganics (RI), Terrestrial ecotoxicity (TE), Global warming (GW), Non-renewable energy (NE) and Mineral extraction (ME).

As shown in Figure 6, the total score for UV-photolysis was higher. Therefore, it becomes evident that the enhanced removal efficiency promoted by addition of hydrogen peroxide and persulfate is the main factor responsible in the reduction of the non-renewable energy impact score.

**Streamlined Life Cycle Costing**

The UV-based treatment systems were also assessed from an economic point of view. Streamlined LCC does not provide the information on the cost of the technology, but it can give a comparison between options under study. The main focus of the LCA is the exploitation of UV-based technologies, therefore, capital costs were excluded. Table 2 shows the operation cost in $ m⁻³ wastewater contaminated with steroid hormones treated with each of the UV-based technology.

Operation cost is dominated by electricity, which is consistent with characteristics of AOP technologies as they are energy intensive processes. The most costly technology for the removal of steroid hormones is direct photolysis. This is mainly caused by the highest power consumption and the lowest efficiency. Therefore, this option is the least economically feasible for the treatment of wastewater contaminated with steroid hormones. The cheapest alternative is UV/persulfate, due to higher efficiency of treatment, which is consistent with the impacts for both technologies. However, several aspects, which can increase the operational costs such as maintenance and personnel, were excluded from the present study.

**Combined results of LCA and LCC as eco-efficiency index (EEI)**

The eco-efficiency index (EEI) has been defined under basic premises: eco-efficiency is considered as the result of minimizing the binomial impact-cost, and environmental and economic aspects must receive the same weighting. This means that decreasing the magnitude
The life cycle impact of an alternative is obtained in the LCA as a normalized set of six indicator scores, namely the environmental profile. Nevertheless, in the EEI environmental impact is defined as unidimensional. Therefore normalization and weighting must be applied, in order to obtain a single impact score in (Pt m⁻³). Table 2 shows the detailed calculation of all the parameters leading to EEI for UV-based technologies under study.

From an integrated environmental-economic point of view, great differences appear between the alternatives for estrogen hormones treatment. The least eco-efficient option is direct photolysis, which reaches the highest EEI score, 1. That means that it is at the same time the most expensive and least environmentally friendly alternative. The most eco-efficient option is UV/persulfate, which has the lowest EEI (0.55), whereas the EEI for UV photolysis combined with hydrogen peroxide was 0.61.

**CONCLUSION**

UV-based treatment systems (e.g. UV-photolysis, UV/hydrogen peroxide and UV/persulfate) were studied for the removal of mixture of steroid hormones (\(17\alpha\)-estradiol, \(17\beta\)-estradiol, \(17\alpha\)-dihydroequilin, \(17\alpha\)-ethinyl estradiol, estriol, estrone, equilin, norgestrel, gestodene, trimestron, medrogestone and progesterone) in aqueous solution. The technological efficiency of the chemically-assisted processes (UV-hydrogen peroxide and UV/persulfate) was higher than UV-photolysis only. Further, combined Life Cycle Assessment and Life Cycle Costing (LCA&LCC) methodology was applied to identify optimal UV-based technology (UV-photolysis, UV/hydrogen peroxide and UV/persulfate) for removal of steroid hormones from aqueous solution. UV-photolysis was found as the least efficient option not only from technological, but also from environmental point of view. UV-based technologies have the environmental impacts in the

<table>
<thead>
<tr>
<th>EEI parameters</th>
<th>UV</th>
<th>UV/hydrogen peroxide</th>
<th>UV/persulfate</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCIAREL</td>
<td>1</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>LCCREL</td>
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<td>0.14</td>
</tr>
<tr>
<td>EEF_E</td>
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<td>0.47</td>
<td>0.48</td>
</tr>
<tr>
<td>EEF_C</td>
<td>0.5</td>
<td>0.14</td>
<td>0.07</td>
</tr>
<tr>
<td>EEI</td>
<td>1</td>
<td>0.61</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 2. Calculation of the Eco-efficiency Index (EEI) for UV-based technologies
following categories: Carcinogens (C), Non-carcinogens (NC), Respiratory inorganics (RI), Terrestrial ecotoxicity (TE), Global warming (GW), Non-renewable energy (NE) and Mineral extraction (ME). The contribution of various subsystems in several impact categories was also assessed. The results of combined LCA&LCC have been summarized as eco-efficiency index (EEI). The results showed that the most eco-efficient option is UV/persulfate, which has the lowest EEI (0.55), the EEI for UV photolysis combined with hydrogen peroxide was 0.61, whereas the EEI for UV-photolysis was 1.

REFERENCES:


ABSTRACT
Increasing worldwide interest for Ultra Violet disinfection systems and the continuous drive to use energy efficient solutions, have positioned the low pressure UV lamps back in the spotlight. Optimizing the design of wiring harness and cables used, can prevent unwanted additional losses and therefore lower UV output.

INTRODUCTION
The low-pressure lamp technology has proven to be 2.5 to 3 times more energy efficient in their capabilities to convert electrical energy to the needed UV light, compared to medium pressure lamps. Despite the drawback of this lower efficiency, the medium pressure lamps however, have unsurpassed power capabilities at small dimensions for the needed equipment. We have seen medium-pressure UV lamps at 35kW used in very compact water disinfection systems.

The “green quest” for more energy efficient systems has led to new low-pressure lamps with power handling of 800 to 1000 watt per (amalgam) lamp. Also new, high-efficient and intelligent lamp drivers to preheat, ignite and power the lamps at various power levels are available now.

Figure 1
Following aspects will become more important for new designs of UV disinfection systems:

- Allow long distances between lamp driver and lamps
- Optimal preheat and starting sequence
- Dimming capabilities, without lowering specified lamp lifetime expectations
- Protect lamp driver for leakage currents, shorts to ground and End of Life (EOL) effects of lamps
- Full control and monitoring of UV lamps

Operation of discharge lamps on High-Frequency Lamp Drivers (Ballasts) offers several advantages over operation on electromagnetic (EM) ballasts operating at 50 or 60 Hertz, especially for LP lamps, as these lamps are 10-15% more efficient at high-frequency operation.

**LAMP WIRING**

The advantages of electronic lamp drivers include higher efficiency, better controllability of lamp power or current, stepless dimming, very low warm up mains current and longer lamp life. To maintain these advantages even at large distances between lamp and driver, the design and specification of the wiring or cable between driver and lamp need extra attention.

The following simplified circuit can be used to discuss lamp wiring effects:

Wiring properties that can degrade performance at high frequencies are:

1. **Cable capacitance.** When lamp drivers use a resonant tank circuit at its output to allow power control and enable ignition, additional capacitance from the cable will cause a shift in operating frequency and could be detrimental for ignition. The capacitance depends on the geometry (conductor diameter and distances) and insulation properties. Nedap electronic lamp drivers can compensate for wiring capacitance over a relative large range of capacitance. Beyond that range the peak ignition voltage will reduce somewhat, as will the efficiency during dimming, due to the additional capacitive output current.

2. **Cable inductance.** The impedance of an inductance is proportional to frequency, so at high frequencies (HF) the voltage drop across this inductance will increase. This voltage drop has a 90° angle to the lamp voltage. The longer the cable and the higher the frequency, the higher the voltage the lamp driver has to supply to maintain the same lamp voltage. Since most lamp drivers will
control lamp power by changing the operating frequency, the increase in lamp driver output voltage will cause a change in operating frequency. Since all lamp drivers have a limited output voltage range in which they can supply maximum power, a too high voltage drop across the wiring will reduce the maximum power that can be delivered to the lamp. A second effect is that the cable inductance, together with the wiring capacitance, will cause additional resonances.

3. **Cable series resistance.** Skin effects (the magnetic field of the HF current causes the current to flow at the outside of the conductor) and proximity effects (the magnetic field of the HF current causes eddy current losses in adjacent conductors) are the cause of an increase in the effective series resistance at higher frequencies. The effect is that for the same current the conductor losses, and therefore cable temperature rise, will be higher for the HF current. This effect depends on the strand diameter and isolation and the number of strands. So for the same wire, the wiring losses at high-frequency operation are higher than at low-frequency operation and a derating factor has to be taken into account.

4. **Cable dielectric losses.** These occur in the insulation material and are (at constant voltage and dissipation factor) proportional to frequency. They add to the total cable losses and temperature rise. PVC types of insulation tend to have higher dielectric losses than e.g. silicone insulation.

**RESULTS**

The increasing losses at high lamp voltages during dimming are mainly caused by the dielectric losses due to the higher frequency during dimming.

Figure 3 shows the impedance parameters of 50m Lapp cable Olflex 150 4x1mm2. The cable was on a reel. This is somewhat comparable to multiple cables placed close together in a conduit.

It can be clearly seen that above 40-50kHz the effective resistance starts to increase and that the inductance has a small decrease. Both effects are due to the skin effect.

The resistance increases from 1.87 Ohm at DC to 1.96 Ohm at 45kHz and 3.68 Ohm at 140kHz. So the current derating factor due to the skin effect at 45kHz is \(\sqrt{\frac{1.87}{1.96}}=0.977\) and at 140kHz is \(\sqrt{\frac{1.87}{3.68}}=0.713\).

The frequency, at which the effective resistance starts to increase, can be shifted upward by choosing wires with more, but thinner strands. Or even better by isolating the individual strands (Litz wire).

In a system using multiple 160W Low Pressure Lamps running nominal at 180V, using 30 meter PVC insulated cable for the lamps, we found following results at a dimming rate of 50% (in power), so at 80W. The measured power at the lamp was only 65W and the cable losses went up to 15W. This means that 19% less power was delivered to the lamp and therefore substantial less UV output was generated. Choosing a lower lamp voltage and the right cable type, the losses could be brought back well below 5%.

**CONCLUSION**

New intelligent lamp drivers are specially designed for higher power levels, optimal ignition, maximal dimming capabilities and allowing longer lamp cables without compromising lamp performance and life expectancy. But shifting to higher operating frequencies to drive the UV lamps will need a new approach for the design of connecting cables between lamps and lamp drivers. Optimizing the lamp cables can prevent overheating of cables due to additional losses and can improve overall performance, efficiency and reliability of UV systems.

Dr. John C. Psaroudis, Robert S. Banker, Ken Kershner
Aquionics Inc., 21 Kenton Lands Road, Erlanger, KY 41018, USA

Key Words: UV; disinfection; swimming pool; chloramine

INTRODUCTION

While UV technology has been used in other industries in the US for many years, the emergence of UV for swimming pools in the US has been more recent, dating back approximately 15 years. Initially, UV was used for removal and control of combined chlorine (chloramines) from indoor pools, with the added benefit of secondary disinfection. Today, growing concerns about the health of patrons has created increased demand for UV in the outdoor pool and spray pad market as well. UV systems are now firmly established as key components for both disinfection and chloramine control.

As stricter codes and regulations are put in place to protect the health and wellness of aquatic patrons, more and more facilities are utilizing UV technology. This article addresses the most common questions asked when owners and operators are considering UV for their new or existing facility. How does UV work? Are there different types of systems available? Are they difficult or expensive to operate? How effective are they? What system is right for our facility? How do we incorporate it into our layout? Before examining the specifics of UV technology, it is helpful to review why it has become indispensable for the safe and efficient operation of virtually every type of aquatic environment.

THE CHLORAMINE PROBLEM

Pool management and maintenance personnel are well aware of the issues related to the presence of chloramines in swimming pool water. Users often incorrectly attribute the familiar odor in a natatorium to too much chlorine in the pool; in reality, the smell results from chloramines in the pool—the undesirable by-product of chemical oxidation in the water. The most conscientious and knowledgeable operators continue to struggle with controlling chloramines, which, if not maintained at low levels, irritate swimmers and foul the natatorium environment.

Historically, the chloramine problem has been managed through plentiful air exchanges, but in recent years, natatorium air handling systems have become more aggressive in limiting the amount of outside air brought into the natatorium in order to maximize energy efficiency. In many modern facilities, therefore, it is not uncommon for airborne chloramines to accumulate, endangering the respiratory health of users and staff.

Airborne chloramines can also result in accelerated corrosion in the natatorium, reducing the life cycle of the building. Maintenance staff must give increased attention to stainless steel deck equipment (lifeguard stands, grab rails, starting blocks, diving board railings, etc.) in order to prevent discoloration and corrosion due to chloramines (See Figure 1). (Stainless steel is definitely not “stainless” in such an environment.) In addition, natatorium air handling equipment can be compromised as air laden with chloramines saturates the system. Thus, the inability to control chloramines in the pool water is more than just an air quality issue for users; damage to the physical plant is likely (and costly) as well.
Management and maintenance staff often treat chloramines in the pool water through a process known as superchlorination, or “shocking” the pool. The chlorine level is raised significantly with the goal of reaching breakpoint. If breakpoint is reached successfully, the chloramines in the pool water are reduced. It sounds easy: determine the amount of chlorine to add to reach breakpoint, add the chlorine at closing, get a good night’s sleep, return to find that the added chlorine has been consumed as it removed the chloramines and that free chlorine level is back to normal, ready for the day’s activities. Most find it isn’t this simple. Maybe the chloramines were reduced slightly; sometimes the chloramines were worse! The blame is usually placed on not reaching breakpoint, so the general practice to guarantee reaching breakpoint is to overshoot breakpoint by adding more chlorine than calculated. Unfortunately, over-dosing the chlorine during this process can have undesirable results also, such as di/tri-chloramine formation. The most active form of free chlorine is hypochlorous acid (HOCl), because the HOCl is 60 to 100 times more effective than hypochlorite ion (OCl-), the other component of free chlorine. Superchlorinating quickly raises the pH, causing more OCl- to form and less of the beneficial HOCl, making matters worse. And if this method of treating chloramines wasn’t difficult enough already, the off-gassing which occurs during the process needs to be removed from the water surface for a successful superchlorination. The result: total frustration for the management/maintenance staff who are trying to be conscientious and provide a healthy experience for all users.

This frustration created a demand for non-chlorine oxidizers that could be used to reduce chloramines. The effectiveness of non-chlorine oxidizers has been debated. The advantage is that there is no breakpoint that needs to be reached; any amount used will treat chloramines until exhausted. The chemical can be added manually or dosed through a dedicated pump. One downside is that any residual oxidizer present in the water is an irritant for swimmers. Also, when testing for the combined chlorine level of the water, this chemical gives a false high combined chlorine reading when a residual is present—exactly what the operator is using the chemical to reduce—possibly leading to over-dosing. Reagents are available to remove this interference, but this potential interference is not well understood by operators. Non-chlorine oxidizers are expensive, and regular use can increase annual budgets substantially.

Another method of controlling chloramines is by adding fresh potable water to a pool. One common practice is to send the pool chemical controller sample stream to waste instead of returning the water to the pool, thereby reducing the volume of the pool and creating a need for fresh fill. Or, the water level is manually dropped periodically and fresh water added. Unfortunately, many cities use chloramines at their water treatment plants, so, in areas where this is done, adding fresh water only increases the problem of chloramines in the pool.

THE ULTRAVIOLET SOLUTION

Controlling chloramines with UV saves the operator time, energy and the chemical costs necessary for superchlorination. Medium pressure UV destroys all chloramines, monochloramines, dichloramines, and nitrogen trichloride (trichloramines), which will be discussed in more detail later. Automatically and consistently minimizing chloramines in the pool water significantly reduces the off-gassing and contamination of the natatorium air, resulting in a healthier and more pleasant indoor environment, along with extended building and equipment life.

While chlorine is still the gold standard in swimming pool disinfection, the rise in bacterial outbreaks and failure to adequately control harmful microorganisms with conventional methods left the industry looking for a reliable secondary form of disinfection. UV, with its powerful ability to kill water-borne bacteria, has now taken the lead in
secondary disinfection in the US and Canada. As recognition of this need increases, UV will only become more prominent as an effective disinfectant, particularly to control Cryptosporidium. In many instances, compliance with updated codes will necessitate adding UV to more traditional sanitizing systems.

While the chloramine control benefits of UV are obvious for indoor pools, UV as a secondary disinfectant is beneficial to every aquatic environment, including outdoor facilities such as activity leisure pools, competition pools, spray pads, therapy pools, tot pools, spas, and plunge pools. The importance of UV for outdoor pools has been recognized nationwide. When a well-publicized Cryptosporidium outbreak occurred in New York several years ago, many state and local governments were forced to change and modify procedures and standards that had been in effect for many years. State spray pad codes have been the most reactive to this situation, and many states now require UV on spray pads. Currently, the CDC has appointed a committee that is trying to create a “standard code” for the aquatics industry known as the Model Aquatic Health Code (MAHC). This has been a long time coming and should at the very least be a guideline for facilities to follow in the absence of other regulations or may replace state codes eventually. Currently in draft form only, the MAHC is addressing the issue of secondary disinfection, and, not surprisingly, UV is one of the preliminary solutions.

UV EXPLAINED

UV systems all come with two major components: the reaction chamber, which houses the UV lamp and a protective quartz sleeve and wiper, and the control cabinet, which is the command center of the system. The reaction chamber will have an intensity monitor and temperature sensor and comes in two styles, in-line and “U” shape. Both have their advantages and disadvantages. The “in-line” systems appear at first glance to be easier to install because the unit can be mounted both vertically and horizontally; however, either type should be installed with a by-pass loop for ease of maintenance and repair. When performing the preventative maintenance it is easier to put the UV in bypass and service the unit without interruption of pool operation. If there is no by-pass installed, the pool pumps and filters must be shut off while the maintenance is conducted.

Due to the contact time being shorter for in-line chambers, these units will require more lamps than a U-shape unit. Power control is also an important consideration; some manufacturers offer dose control in which the UV automatically adjusts to water conditions by ramping up or down to different power levels. Other manufacturers offer a feature known as 50% power-down. The UV runs at either 100% or 50%. Both methods are designed to save energy costs and extend the lamp life. The power-down is typically operated by a timer that puts the unit in power-down during the evening. Recently, a couple manufacturers are promoting running the UV power-down from a chemical controller combined chlorine reading. Additional probes are required for this system, namely a ppm and total chlorine probe. Other system considerations include the kW power of a UV system, type of ballast, type of automatic wiper mechanism, the voltage the unit can run on, and manufacturer warranty and support.
cy of the filtration system turnover rate in trying to combat this problem. When utilizing UV, the laws of dilution state that it takes four turnovers to treat 98% of the water. Today, aquatic consultants have recognized the need for faster turnovers for high-use pools and spas, and some state codes are requiring faster turnovers for specialty pools and spray pads. A faster turnover benefits the UV’s ongoing disinfection capability. If a tot pool has a 30 minute turnover, 98% of the water is treated every two hours; a spa on a 15 minute turnover will treat 98% of the water every hour. Leisure pools are typically designed in the 2-3 hour turnover rate range, meaning every 8-12 hours that body of water is being disinfected by the UV. Years ago pools were designed to meet codes requiring a 6-8 hour turnover. Most codes will allow a six hour turnover for competition pools. Regardless of the turnover rate, during the four turnover time span, some of the water will be treated several times, and some will be treated only once, which allows for untreated monochloramines to convert to di’s and tri’s continuously.

LOW OR MEDIUM PRESSURE?
Which system to use for effective control will depend on a number of factors, including the size of the body of water and the turnover rate. Both Low Pressure (LP) – monochromatic and Medium Pressure (MP) – polychromatic UV systems are effective as far as disinfection is concerned, and both methodologies have been found to be effective in controlling the harmful bacteria and pathogens associated with swimming pools and spray pads. Both provide the 254 nm wavelength required for disinfection. There have been many studies done regarding the effectiveness of low pressure and medium pressure systems for the inactivation of Cryptosporidium. In dealing solely with disinfection of swimming pool and spraypad water, either LP or MP prove to be similar in efficacy; however, with respect to chloramine destruction, there are some differences in technology.

UV does not replace the need for chlorine, as chlorine is an excellent disinfectant providing the instant kill for many harmful pathogens. But, unfortunately, some pathogens are resistant to chlorine, the most notable being Cryptosporidium and Giardia. Information from the CDC states that 1.0 ppm free chlorine level with a 7.5 pH will take 6.7 days to effectively treat Cryptosporidium. LP UV provides a 254 nm wavelength which is adequate for disinfection and destruction of monochloramines (which are absorbed at a wavelength near 245 nm). Spas and smaller pools tend to do better with LP units than the larger and high bather loaded pools because the turnover rates are generally faster (15-30 minutes for spas), so the water tends to be treated more often and the LP units have an easier time keeping up with the demand. The most harmful and annoying di (297 nm) and tri (340 nm) chloramines can only be removed by the MP polychromatic systems.

There are many differences and selling points to LP and MP that need to be addressed as well. LP units don’t remove as much free chlorine as the MP units do, so there is a savings in chemical usage. LP units can operate at a lower electrical cost because they are using less energy than MP. LP units require more lamps than comparable MP units. Some MP units are capable of treating a flow rate of nearly 1,400 gpm with a single lamp which would take most LP units about 8-12 lamps, so the lamp replacement costs are less for MP.
Low pressure systems do not need automatic wipers for the quartz sleeves as do the MP units. MP first dollar costs are typically higher than comparable LP systems. LP chambers are available in Schedule 80 PVC as opposed to MP only being available in 316L stainless steel. Automatic wipers on the MP systems will need occasional maintenance. LP sleeves will need to be cleaned from time to time by manually removing the sleeves or running an acid solution through the chamber. Some factors to consider when determining the desirability of LP or MP for a given application are: whether the facility is indoor or outdoor; whether it requires disinfection and chloramine control or disinfection only; and ongoing costs of LP and MP, to name a few. As a rule of thumb, each facility should be treated independently when in the design phase to give the owner the greatest benefit for the money.

EQUIPMENT ROOM DESIGN CONSIDERATIONS
As for the sizing, design and placement of the UV system in the filter room, there are many factors that need to be taken into consideration. First and foremost, it is imperative to select the correct model for the pool being treated, taking into consideration the flow rate, the return to pool pipe diameter, type of pool being treated (therapy pool, spa, competition pool etc), bather load, and method of disinfection (salt, bromine, or chlorine), as well as the footprint of the filter room. UV is not just for new construction. When UV is being considered for an existing facility, a UV system can be easily added to the current mechanical system due to the minimal space requirements.

Placement of each system is relatively easy. On new facilities, simply place the UV system on the return to pool line, after the filter and before the peripheral equipment such as heat exchangers and HVAC lines, and chemical injection ports. One of the differences between treating pool water and other types of water is that pool water is usually on a loop. The water goes from the pool to the filter and back to the pool again. In other applications, the water gets treated and is then used or sent to waste. Pool water is recirculated, therefore it has the opportunity to be treated repeatedly by the UV.

The UV treatment will be most efficient when the water entering the unit is as clean as possible. To that end, the water will come from the pool and go through the hair/lint strainer, filter, UV, peripherals, and back to the pool. When you are placing a system on an existing facility it can be harder to place the unit exactly where you want it, so it can be placed anywhere in line after the filter. The water should still be at its best possible when treating it with UV.

SUMMARY
UV provides healthier water due to chloramine destruction and disinfection and increased user comfort. If the UV controls the proliferation of chloramines, there is no longer a need to superchlorinate the pool. Free chlorine is more efficient since the UV is helping with the workload of the chlorine, and the free chlorine can thus be maintained at lower levels. Due to reduced chlorine use, fewer chlorinated by-products are formed, less pH buffer is required, and less total alkalinity adjustment chemicals are needed. Overall, fewer chemicals are added to the water which is beneficial for any type pool. With UV, the life cycle of the building envelope and HVAC system may be extended, as well as the life cycle of pool deck equipment. Less fresh water addition may be needed and less natatorium maintenance will be necessary for cleaning stainless steel deck equipment. In addition, operators have been pleasantly surprised by UV’s ease of operation along with its effectiveness.
ENVIRONMENTAL CONTAMINANT TREATMENT

Or ECT, for short. It’s the advanced treatment of contaminants, including taste and odor-causing compounds, nitrosamines, pesticides and algal toxins. The TrojanUVSwift™ ECT and TrojanUVPhox™ are our ECT solutions. These sophisticated systems are relied upon – by municipalities around the world – to eliminate chlorine-resistant protozoa and destroy harmful chemical contaminants in drinking water, reclaimed wastewater and contaminated groundwater.

UV-oxidation, indirect potable reuse and reduced water stress. That’s UV innovation. That’s TrojanUV Environmental Contaminant Treatment.

Find the answers at trojanuv.com/ect.
The need for clean water
Many people are concerned with the quality of water, because microorganisms present in water can make them ill. In emerging economies the water infrastructure is often to blame, yet even in developed countries incidents of contamination still occur. As one study shows, in North America alone 85% of sicknesses in children and 65% of adult diseases are a result of waterborne viruses and bacteria¹.

Disinfection of water
UV technology is a natural way to make sure water is safe to drink. UVC deactivates microorganisms, rendering them harmless. It is effective against all types of bacteria, viruses and protozoa and there are no known pathogens resistant to it. Moreover, it does not add chemicals or other additives that may be harmful to human health or the environment. It doesn’t alter the taste, pH value or other properties of the water either.

InstantTrust: a new cutting-edge disinfection technology
Philips has developed a complete disinfection solution for point-of-use equipment based on a patented disinfection technology – InstantTrust. It breaks new ground, overcoming four key limitations of existing UV disinfection systems: size, run-up time, temperature sensitivity and environmental impact. InstantTrust is half the size or less of existing disinfection functions, which means it can be built into almost any POU application, from fixed taps to portable pitchers. Moreover, it provides an instant start with no run-up period so that safe water is delivered from the very first second onwards – eliminating waiting time and the risk that the water is not always disinfected. It can be used for both cold (4°C) and hot water applications – an industry first – thanks to its constant temperature curve. From an environmental perspective it is completely mercury free.

A broad range of applications
With demand for residential purifiers increasing every day², this new technology with its promise of almost complete design freedom comes at a good time. Its benefits make it ideally suited for instantly disinfecting small quantities of cold water (up to 4 liters/minute) taken from dispensing equipment such as bottle refill stations, bottled water dispensers and for example. Other point-of-use applications include hot and cold water systems with taps and under-the-sink water treatment systems.

With the introduction of InstantTrust, Philips has a unique and innovative UV-based water disinfection solution that improves access to safe drinking water around the world.

¹ UV Disinfection (Source: Excel Water Technologies)
² Global Competitive Environment for Residential Water Treatment Equipment Markets (Source: Frost & Sullivan 2005)