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UV FOR WASTEWATER TREATMENT

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Message from the President –
Bob Hulsey
WHERE IS IUVA GOING?

It is important to have a plan. Returning home invigorated from our 2nd World Congress in beautiful Vienna and an exciting side trip to the DVGW validation test facility, the first thing on my mind was, how can our organization continue to grow and serve more people who are interested in the varied application of ultraviolet radiation? Actually, the first thing on my mind was getting through U.S. Customs with my package of Black Forest ham, but that’s beside the point (FYI – Customs confiscated the ham). Back to the subject – our organization continues to grow in both size and stature among UV aficionados. We need to be ready for expansion in terms of how the organization is structured and what services we provide. That’s where the plan comes in.

The core executive board (yours truly, our secretary/executive director Jim Bolton, and treasurer Chris Schulz) has started to develop a business plan to determine where the IUVA is now, where it should go, and what is the best path to take us there. In a nutshell, it will address the following matters:

- **Target Applications** – which areas of UV interest can we serve.
- **Industry Services** – what role we should play in promoting research, standards of practice, and organizing information for each area of interest.
- **Membership** – for those areas of interest, what membership can we expect.
- **Membership Benefits** – how do we serve our members through workshops, conferences, and publications.
- **Organization** – how the organization should be structured to provide these services in a cost-effective manner.

I recall Jim Malley saying throughout his tenure as president, “This is your organization, it will go wherever you will take it.” I am a firm believer in this concept, but to make it work, we need to hear from you as this plan takes shape. Please send us your thoughts on what you would like to see us do and how we should go about doing it. My e-mail is always open – hulseyra@bv.com - and keep your eye on this corner to see how the plan progresses.

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Upcoming Issues

IUVA News print version appears quarterly and publishes contributed articles on any and all aspects of ultraviolet technology. Your Editors solicit articles and advertisements for publication. For 2003 issues, any paid advertisement run in one issue of the print version can be run in TWO issues of the electronic version at no charge. Please contact either Rip Rice or Jim Bolton (see below) with (a) intentions to submit, (b) written contributions, or (c) advertisements (item “c” to Rip Rice).

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Reduction Rates of Pathogens and Fecal Indicators After UV Disinfection at the Bad Tölz (Germany) Wastewater Treatment Plant

Stefanie Huber and Wolfgang Popp
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ABSTRACT
In this study, reduction rates of selected pathogenic microorganisms after UV disinfection at a wastewater treatment plant are compared to reduction rates of fecal indicator bacteria. Levels of coliforms and fecal streptococci are reduced by approximately 5 and 4 log-units, respectively. Similar rates are found for somatic coliphages as model organisms for enteropathogenic viruses. However, spore-forming Clostridium perfringens is more resistant to UV irradiation. Reduction rate investigations for Salmonella spp., Campylobacter spp., F-specific bacteriophages and protozoan parasites Cryptosporidium spp. and Giardia spp. presently are under way.

INTRODUCTION
Monitoring of fecal pollution of bathing waters by health authorities generally is based on the determination of fecal indicator bacteria. To reliably prevent health risks, enteropathogen reduction by wastewater disinfection measures should at least be in the same range as fecal indicator reduction. Within our bathing water restoration project at the Upper Isar river, an accompanying study compares the reduction rates of fecal indicators to those of selected pathogenic microorganisms achieved by a UV disinfection system at the Bad Tölz wastewater treatment plant (82,000 Population Equivalent, dry weather flow: 510 m³/h). The disinfection unit (144 low-pressure UV lamps, 125 W each, 254 nm) is operated during the bathing season only (mid April to end of September).

In 2002 (July to September) the reduction rates of fecal indicators, Salmonella spp., Clostridium perfringens, somatic coliphages, Cryptosporidium spp. and Giardia spp. were studied. Campylobacter spp. and F-specific bacteriophages were included in 2003.

MATERIAL AND METHODS
Samples
From July to September 2002 (usually fortnightly), effluent samples were taken from the Bad Tölz WWTP before and after the UV disinfection unit.

Fecal Indicators
Total and fecal coliforms were detected with an MPN method (3 dilutions with 3 parallels each). The diluted samples (1 mL) were incubated in 10 mL lauryl sulfate broth (Merck 1.12588) at 37°C for 48 h, 0.5 mL 1 N NaOH was added to total coliforms positive (gas production) test tubes. Tubes which show fluorescence under UV light (360 nm) are regarded as being positive for fecal coliforms. The detection of fecal streptococci was performed according to ISO 7899-2. After membrane filtration, the filters were placed on enterococcus agar according to Slanetz and Bartley (Merck 1.05285), the plates were incubated at 37°C for 48 h. The filters then were transferred to bile esculin azide agar (Difco 0525-17) and incubated for another 2 h at 44°C. Colonies that impart a dark brown color to the medium are counted.

Salmonella spp.
The detection of Salmonella spp. was performed according to the draft of ISO DIS 6340. After membrane filtration and a preenrichment step in buffered peptone water (Merck 1.07228), Rappaport-Vassiliadis broth (RVS, Merck 1.07700) was inoculated with the preenriched culture. After this selective enrichment the cultures were plated on XLD (Xylose Lysine Desoxycholate) agar (Merck 1.05287) and Rambach agar (Merck 1.07500). Colonies of presumptive Salmonella were confirmed with urea rogor (Merck 1.08492), BBL Enterotubes II (BD 273176) and Wellcolex Color Salmonella Kit (Genzyme Virotech HW/30858302).

Due to isolation problems, some parameters were varied: RVS broth was inoculated with different amounts of preenriched culture, and novobiocin was added to both RVS and XLD. Additionally, efficacy of direct inoculation of the sample in selective medium (RVS) was tested.

Clostridium Perfringens
The wastewater samples were filtered through a membrane filter (0.45 μm). C. perfringens was enumerated on mCP (membrane Clostridium perfringens)-agar (Oxoid CM0992B and SR0188E) after incubation in an anaerobic jar (with AnaeroGel®, A, Merck 1.13829) at 44°C for 24 h. Colonies that turned from yellow to pink after exposure to ammonium hydroxide vapors for 20 to 30 s were counted.

Campylobacter spp.
Filters were placed in Preston broth (Oxoid CM0067B, SR0048C, SR0084E, SR0117E) and incubated at 37°C for 48 h in anaerobic jars (oxygen reduced atmosphere,
Anaerocult C, Merck 1.16275). The cultures were plated on mCCDA agar (*Campylobacter* blood-free selective agar base + CCDA selective supplement, Oxoid CM0739B and SR0155E) and incubated at 37°C for another 48 h in the modified atmosphere (Anaerocult C). Presumptive colonies of *Campylobacter* spp. were checked microscopically for typical appearance.

**Somatic Coliphages and F-specific Bacteriophages**
For the enumeration of somatic coliphages and F-specific bacteriophages European Norms EN ISO 10705-1 and 10705-2 were used without modifications. Host strains for somatic coliphages and F-specific bacteriophages were *Escherichia coli* DSM 12242 and *Salmonella* choleraesuis subsp. choleraesuis serotype *Typhimurium* WG49 (ATCC 700730), respectively.

**Cryptosporidium spp. and Giardia spp.**
The detection of Cryptosporidium oocysts and Giardia cysts was performed according to the English Standard Method (Drinking Water Inspectorate: *Cryptosporidium* – Legal Requirements and Standard Operating Protocols, Parts 2 and 3; http://www.dwi.uk/regs/crypto/legalindex.htm) at the University of Tübingen. Samples were taken by pumping 50 to 100 L of wastewater through Genera Filta Max filters.

**RESULTS**

**Reduction of Fecal Indicators**
Figure 1 shows the numbers of total coliforms, fecal coliforms and fecal streptococci in 100 mL wastewater before and after UV irradiation on a logarithmic scale.

Total coliform levels (concentration before UV irradiation $N_0 = 10^5$ to $10^6$ MPN/100 mL) were reduced by 4.9 ± 0.5 log-units, fecal coliforms ($N_0 = 10^4$ to $10^5$ MPN/100 mL) by 5.0 ± 0.6 log-units and fecal streptococci ($N_0 = 10^4$ to $10^5$ cfu/100 mL) by 3.7 ± 0.3 log-units. (Note that the number of streptococci after UV irradiation was not zero on 03/09/02, 17/09/02, 30/09/02 and 12/05/03, but 100 (±1) cfu/100 mL).

**Reduction of Salmonella spp.**
Isolation of Salmonella spp. turned out to be somewhat problematic due to the great amount of accompanying flora in wastewater samples. Therefore there are no quantitative results about the reduction of salmonellae after UV disinfection at Bad Tölz so far. Adding of novobiocin to the media or direct inoculation of the sample in selective medium did not improve isolation efficacy. Inoculation of selective medium (10 mL RVS) with 0.1 mL of preenriched culture turned out to be superior to 1 ml.

**Reduction of Clostridium perfringens**
*Clostridium perfringens* ($N_0 = 10^2$ to $10^3$ cfu/100 mL) was reduced by an average of 0.9 ± 0.3 log-units in the UV disinfection system at the Bad Tölz WWTP (see Figure 2).

**Reduction of Somatic Coliphages**
Values between $1.1 \times 10^9$ and $4.1 \times 10^9$ pfu/100 mL were found in effluents before UV irradiation, whereas in irradiated 100 mL samples plaque forming units were never detected. Consequently the reduction rate is higher than 4 log-units.

![Figure 1. Numbers of fecal indicator bacteria in effluents of Bad Tölz WWTP before and after UV irradiation.](image-url)
Reduction of Cryptosporidium oocysts and Giardia Cysts

In 2002 three samples were sent to the University of Tübingen for detection of Cryptosporidium oocysts and Giardia cysts. In the first sample (August 2002), no oocysts were found. The concentration of cysts after UV irradiation was higher (by 0.5 log-unit) than before irradiation in this sample. The other two samples (September 2002) showed reduction rates of 1.0 and 0.4 log-units for oocysts and 0.6 and 0.4 log-units for cysts, respectively (Cryptosporidium: N₀ = 10 and 1 oocysts/L; Giardia: N₀ = 7 and 4 cysts/L).

Reduction of Campylobacter spp. and F-Specific Bacteriophages

First results in 2003 indicate reduction rates of more than 3 log-units for Campylobacter spp. and about 2 log-units for F-specific bacteriophages. Concentrations before UV irradiation are in the range of 10³ KBE/100 mL and 10¹ pfu/100 mL, respectively.

DISCUSSION

In contrast to the high reduction rates for fecal indicator bacteria with about 5 log-units for total and fecal coliforms and about 4 log-units for fecal streptococci after the UV disinfection unit at the Bad Tölz WWTP, Clostridium perfringens is reduced by approximately 1 log-unit only. It has to be noticed though, that the concentration of C. perfringens is lower than the concentration of fecal indicators in the effluents before irradiation. As a spore-forming bacterium, C. perfringens is relatively insensitive against ultraviolet radiation. Higher resistance of spores (usually of Bacillus subtilis) compared to vegetative cells was found in several studies with laboratory scale UV disinfection units (e.g., Chang et al. 1985, Sommer et al. 1989).

Although there are no quantitative results for Salmonella spp. and Campylobacter spp. so far, these two species will probably show reduction rates in the same range of other non-spore-forming bacteria like coliforms and streptococci. More data will be available after the 2003 bathing season.

Levels of somatic coliphages were reduced efficiently by more than 4 log-units in the effluents of the Bad Tölz WWTP. Coliphages were chosen as model organisms for enteropathogenic viruses. However, viruses vary in their resistance against UV rays (Havelaar et al. 1991), thus the more resistant (compared to somatic coliphages) F-specific bacteriophages have been investigated additionally since May 2003. First results indicate lower reduction rates (about 2 log-units).
For Cryptosporidium spp. and Giardia spp. the data base is still small. These protozoan parasites form oocysts and cysts, respectively, which are highly resistant to various disinfection methods like ozone and chlorine (Korich et al. 1990). The reduction rates of less than 1 log-unit detected in 2002 corroborate those findings. However, recent studies (Morita et al., 2002) show that Cryptosporidium oocysts are often viable but not infective after UV irradiation. It is not possible to differentiate between infective and non-infective oocysts with the detection method (immunofluorescence microscopy) used in the last season. A cell culture assay would be much more reasonable. Currently, cooperation with an institute capable of applying this method is planned.

CONCLUSIONS
The reduction rates of fecal indicator bacteria after UV disinfection of wastewater are suitable to predict reduction rates of pathogenic non-spore-forming bacteria and some groups of pathogenic viruses (represented by somatic coliphages). Other pathogens like spore-forming bacteria, some viruses and protozoan parasites possibly will show lower rates. A more comprehensive data base for these organisms is needed.

References


IUVA Sponsors UV Air Treatment Conference
IUVA is sponsoring a One-Day Conference on Ultraviolet Air Treatment, 6 November 2003 at the Radisson Hotel near the O'Hare Airport in Chicago, IL. This Conference will address the use of UV Technologies to disinfect air and also to decontaminate air. Dr. Wally Kowalski from Pennsylvania State University will give a Plenary Talk on “UVGI Air Disinfection for Commercial, Health Care, and Biodefense Applications”. The deadline for submission of a one-page abstract is 30 September 2003. Please send to the Organizer, Jim Bolton, at jbolton@iuva.org. For further information, contact Jim Bolton at jbolton@iuva.org.
TROUBLE SHOOTING UV SYSTEMS – What To Do When The Lights Go Out?

Gary Hunter and Jorj Long
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ABSTRACT
Over the past ten years, ultraviolet (UV) technology has become a commonly applied method of disinfecting of wastewater effluent. UV disinfection involves passing wastewater effluent through a confined chamber with rows of underwater lamps emitting UV energy. Viruses and bacteria become inactivated upon exposure to dosages of UV energy, thereby disinfecting the wastewater.

The UV system is defined by the physical (electrical and mechanical) requirements of the equipment. These requirements must be matched with the water quality of the wastewater plant to provide effective disinfection. For the purpose of trouble-shooting UV equipment, the UV system can be divided into three components: process, electrical, and mechanical. The process system deals with the quality of the water to be treated by the UV system and the disinfection goals that must be attained. The electrical system consists of the lamps, wiring, and control system. The mechanical system includes the quartz sleeves, frames, cleaning mechanism, and reactor configuration.

When the UV system functions as intended, it is easy for operations staff to maintain compliance with the treatment facility’s NPDES (National Pollution Discharge Elimination System) permit requirements. Responses to the UV troubleshooting question in the 2001 Operations Challenge indicate that WWTP (WasteWater Treatment Plant) operators need additional information on troubleshooting UV systems. When UV systems fail to achieve the desired results, their electrical, mechanical, and process controls need to be examined to identify the cause(s) of the failure and to take appropriate corrective actions.

BACKGROUND
Over the past several years, ultraviolet (UV) radiation has become a preferred disinfection method of many wastewater treatment facility operators. UV disinfection involves passing wastewater effluent through a confined chamber lined with rows of underwater lamps emitting UV radiation. The dosages of UV energy inactivate the viruses and bacteria in the wastewater, thus producing a disinfected effluent.

A disinfection system consists of a power supply, reactor, lamps, a cleaning system (if applicable), a mechanical system to hold the lamps, a controls system, and an electrical system to supply power. The UV lamps that constitute the system are enclosed in individual quartz sleeves to protect them against damage. Over time, the quartz sleeves become coated with deposits of solids carried in the wastewater. Removal of such deposits by either mechanical or chemical cleaning is the primary maintenance task in the operation of UV systems. Another regular maintenance task is replacement of the UV lamps and ballasts.

The intensity of UV radiation is measured by using a monitoring system with sensors. When the UV intensity drops below a given set point, the system control will indicate the need for cleaning. This system also is used in combination with flow signals in some UV systems to control the applied dose.

Reactor chambers (either open or enclosed channels) are equipped with UV lamps in a horizontal or vertical configuration. In an open channel system, the effluent weirs or automatic level control devices maintain the submergence of the lamps. The UV system also may be housed in a structure that shields it from the elements.

OPERATION OF UV SYSTEMS
WWTP operating staff should receive training in the proper operation of the UV equipment. The system manufacturer should provide the training, as each manufacturer has issues that are specific to its system. Key items to be addressed during training are listed in Table 1.

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The plant staff should review the operation and maintenance manuals for the equipment before the training sessions begin. Manuals also should be reviewed following training to determine what materials may be missing or need to be clarified before the manuals are finalized.
PROCESS CONTROL MODIFICATIONS

The effectiveness of a UV disinfection system depends on influent wastewater characteristics and on the upstream treatment processes. Industrial users may discharge substances such as coffee that inhibit the performance of the UV system, and upstream operations may contribute additional solids or organic materials that interfere with disinfection. Table 2 presents a checklist for the UV system.

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Effluent Transmittance

Transmittance is one of the key operating parameters of a UV system. When the UV system fails to attain the required inactivation of bacteria, one of the first conditions to be checked is transmittance to determine when the bacteria limit may have been exceeded, and to compare the results with the design system conditions. Figure 1 shows the values recorded by an on-line transmittance monitor for 12 months at a UV system located in Florida. The design transmittance for the treatment plant was 49 percent.

![Figure 1. Plot of UV transmittance data.](image)

Effluent Total Suspended Solids Concentration

High concentrations of effluent total suspended solids can affect adversely the performance a disinfection system. When the UV disinfection system fails to attain the bacterial inactivation specified in the WWTP discharge permit, excessive concentrations of solids may be the cause. Suspended solids can shield the bacteria against inactivation by the UV light.

One method of evaluating impacts of solids on the UV system is to use the solids concentration in the treatment plant effluent as a baseline. Figure 3 presents data from a treatment plant in Kansas which had discovered that the solids concentration was increasing over time and impairing the ability of the UV system to comply with the plant’s discharge permit.

![Figure 3. Historical effluent TSS concentrations.](image)

At another treatment plant, excess solids were being discharged from the final clarifiers and were settling in the UV reactors. Plant personnel adjusted their maintenance schedule to provide more frequent cleaning of the UV reactor. This simple change improved the UV system performance and restored compliance with its NDPES permit.

UV Spectra

One of the new methods of identifying problems with UV systems is examination of the UV spectra. This can be especially helpful for troubleshooting a medium-pressure
UV system. The HACH 4000 system shown in Figure 4 can be programmed to produce UV spectra of wastewater samples. A baseline of information should be compiled for comparison with samples collected during periods of non-compliance.

![Figure 4. HACH 4000 spectrophotometer for UV spectra.](image)

**Effluent Color**
Effluent color can become a problem if the treatment plant receives effluent from either a paper mill or textile mill. The colored water can absorb UV radiation, which may lead to non-compliance with the discharge permit.

**Industrial Dischargers**
If the on-line UV transmittance monitor is reporting low values and the laboratory has verified the reported values, then the POTW may want to examine the types of industrial dischargers connected to the treatment plant. In some cases the discharge from industry may still be colorless, but impact UV transmittance.

**Algae**
Algae can become a nuisance at POTWs that use UV, especially those that use medium pressure systems. Algae can grow and collect on the sides of the UV reactor to the point that it begins to block flow through the system. Figure 5 illustrates the impact of algae on a UV system.

![Figure 5. Algae in a medium-pressure UV facility.](image)

At one facility the algae growth was so profuse that it plugged the reactor. Plant operating staff has implemented a weekly cleaning schedule for cleaning the reactor to control the growth of algae.

**Iron/Manganese/Hardness**
The operating temperatures of UV systems, especially medium-pressure systems, are favorable to the formation of deposits of iron, manganese, and hardness. These deposits can interfere with the performance of the system, if they are not removed on a frequent schedule.

**Microbial Testing Procedures**
Microbial testing is the key to monitoring the performance of any disinfectant. If appropriate sampling procedures (40 CFR 136) are not followed either in the field or in the laboratory, results can be misleading. Samples should be placed in certified, clean containers using grab techniques and should be kept at a temperature of 4°C during transportation to the laboratory. Analysis should start within 6 hours of the time of collection. In some cases, rosolic acid may need to be added to the sample to ensure accurate counts. After collection, filled sample bottles must be kept in the dark at all times. This can be accomplished by wrapping the bottles in aluminum foil.

**ELECTRICAL SYSTEM MODIFICATIONS**
Table 3 lists items to be checked by plant operations if the problems appear to be related to the electrical system.

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**Lamps Are Energized**
One of the easiest items to check when troubleshooting a UV system is to determine whether the system is on. While this may seem like a very simple task, it is one that is overlooked the most often. In one community, the UV lamps de-energized due to a power surge. Operations staff walked by the system for a week without noticing that it had not been turned back on. One of the first items to check in the event of a compliance problem is whether the lamps have been turned on.

**Lamps Are Connected**
When lamps are replaced they need to be disconnected from the power supply. If the lamps are not reconnected, the system cannot operate. All electrical connections need to be checked to ensure that (1) power is flowing and (2) the system is delivering the correct amperage.

**Useful Lamp Life**
Most UV control systems include a feature that tracks the operating time of the lamps. Once the lamp begins to
approach the end of its useful life, system performance data needs to be watched carefully to ensure that compliance problems do not develop. Lamps need to be replaced when they have reached the end of their useful lives.

**Ballast Output**
The ballast can be labeled as the heart of the UV system. If the ballasts fail to operate, the lamps will not turn on. The electrical output of the ballast may need to be checked to verify proper system settings.

Some manufacturers can provide the electrical output of the system. If the output is too high, the lamps may need to be replaced more frequently. If the output is too low, the system may not be able to achieve compliance with its NPDES permit.

**MECHANICAL SYSTEM MODIFICATIONS**
Mechanical systems are critical to the operation of UV systems and some of the checks are listed in Table 4. Quartz sleeves have to be cleaned on a regular basis. The primary maintenance task required in the operation of UV systems is cleaning the surfaces of the quartz sleeves, due to the tendency of constituents in wastewater to foul the surfaces of the quartz sleeves. Consequently, mechanical and chemical cleaning systems are used periodically to clean the sleeves. Cleaning requirements are based on the reduction in measured intensity caused by the impedance of the transfer of UV light into the bulk wastewater.

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**Cleaning System To Ensure Acceptable Performance**
Deposits on the quartz sleeves will impede the transfer of UV into the wastewater. The deposits are removed using manual, mechanical, or mechanical/chemical cleaning systems. Quartz sleeves should be examined visually to determine if all deposits have been removed. A couple of times per year, the quartz sleeves should be cleaned manually.

**Proper Delivery Of Chemical**
Some UV cleaning systems incorporate both mechanical wiping and chemical cleaning. Medium pressure systems require a mechanical and chemical cleaning system due to the high operating temperature (1,100°F). For these systems to be effective, chemical must be delivered during...
the mechanical wiping of the sleeve. If the chemical sleeve is empty or plugged, it will not provide an effective wiping of the deposit from the quartz sleeve.

**On-Line Transmittance Measurements**

On-line instrumentation needs to be checked and calibrated. Flowmeters and UV intensity and transmittance probes have to be cleaned and maintained on a regular basis. On-line instrumentation measurements are verified with bench-scale equipment to ensure accuracy of the data. Sensor location also needs to be checked to ensure that representative measurements are being collected. Figure 6 shows an on-line transmittance system.

![Figure 6. On-line transmittance measuring system.](image)

**On-Line Intensity Measurements**

On-line intensity measurements can be used to control the dose delivered by the system as well as the frequency of cleaning of the quartz sleeves. Intensity measurements also are used to control the dose in addition to determining when lamps need to be replaced. Therefore, the validity of measurements from this instrument is critical to the operation of the UV system. Intensity sensors need to checked frequently and may need to be replaced annually.

**Flow Meter Calibration**

In order to determine the UV dose being applied to the wastewater, flow information must be transmitted to the PLC. If the flow information is incorrect, the dose may be too high or too low. Information from the flowmeter manufacturer should be consulted as to how often the flow meter has to be calibrated.

**Ballast Cooling System**

All UV systems use electronic ballasts to energize the lamps. The ballasts normally are located above the water line and are aligned one-to-one to the lamps. Some systems utilize a closed loop cooling system which pumps antifreeze through a coolant radiator. The ballasts are attached to the radiator and the antifreeze transfers the heat from the ballasts to the water or air, depending on the system design.

**SUMMARY**

Troubleshooting UV systems is a complicated undertaking. There are many reasons why systems fail to meet their performance requirements. The checklists in this paper can be used to guide operating staff as to the causes of non-compliance. Using the checklists, operating staff can determine what to do when the lights go out.

**ACKNOWLEDGEMENTS**

The authors appreciate the peer review provided by Dr. Vic Moreland, Dr. Elliot Whitby, Gary Neun, and Steve Wolfe.

**Reference**

ABSTRACT
The NSF/EPA Environmental Technology Verification (ETV) Center provides independent performance evaluations of drinking water technologies to accelerate a technology’s entrance into the commercial marketplace by providing consumers with verified results of product evaluations. Two EPA/NSF ETV Program reports were recently prepared to verify the performance of one low pressure (Atlantic Ultraviolet Corporation) and one medium pressure (Trojan Technologies) ultraviolet (UV) system. Testing was conducted at the City of San Diego’s Aqua 2000 Research Center located in Chula Vista, California, using treated Otay Lake filtered water as feedwater. Otay Lake water is characterized by relatively high hardness and pH values, which can contribute to scaling/fouling of the lamp sleeves, and has elevated levels of organic material, which can result in low transmittance. At 100% lamp power, UV transmittance of 90.6%, the low-pressure system was able to inactivate 1.2 to 2.1 logs of MS2 virus at 350 gpm. The medium pressure system was able to inactivate 2.7 to 3.0 logs of MS2 virus at 695 gpm, with the lamp power set at 81% and a UV transmittance of 84%.

INTRODUCTION
Rapid developments in regulatory requirements as well as the identification of emerging pollutants and pathogens, have resulted in the need to install new treatment technologies that lack historical performance data. In order for regulatory agencies to approve the design and installation of these new technologies, however, manufacturers must be able to provide independent third-party verification of their performance claims. Frequently, the process design and installed system performance must also be validated through an approved field commissioning study.

In order to meet the control requirements specified for Cryptosporidium parvum in the draft Stage 2 Long-Term Enhanced Surface Water Treatment Rule (LT2ESWTR) and the disinfection byproduct reduction requirements of the draft Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR), many water agencies have begun design and construction of ultraviolet light (UV) facilities. Although the application of UV has been integrated into the list of technologies available for waste-water disinfection, new developments in lamp technology and reactor design, water quality differences between water and wastewater, and the heightened sensitivity of the public to drinking water issues, has prevented the direct translation of historical wastewater performance data to the drinking water field. Consequently, drinking water systems will require a significant level of testing in order to demonstrate that they fulfill the manufacturers’ claims about dose delivery, process control, system reliability, and long-term performance.

NSF International (NSF), in partnership with the United States Environmental Protection Agency (USEPA) provides independent performance evaluations of drinking water technologies through the Environmental Technology Verification (ETV) Program. The purpose of this program is to accelerate a technology’s entrance into the commercial marketplace by providing consumers with independent third-party verifications results of product evaluations. The USEPA is presently developing a UV Disinfection Guidance Manual to provide assistance in the design, testing, and operation of UV systems for compliance with drinking water disinfection requirements.

MATERIALS AND METHODS
NSF published the first verification testing of UV technology in May 1999 for a medium-pressure Calgon Carbon Corporation Sentinel Ultraviolet Reactor. Two new systems have been passed through the ETV program. Pictures of each system, are shown in Figure 1, Trojan Technologies UVSwift Model 4L12, and Figure 2, Atlantic UV Megatron Model M250.

The Trojan Technologies UVSwift 4L12 contained four 2.8 kilowatt medium pressure UV lamps perpendicular to flow and the unit had flanged fittings for in-line mounting in 12-inch pipe. The system also included a proprietary flow-modifying baffle plate that mounted on the inlet to the reactor. The unit included one UV irradiance sensor that measured the output from one lamp and could be verified against a calibrated reference sensor.

The Atlantic UV Megatron M250 consisted of a 12-in diameter stainless steel chamber which contained nineteen (19)
G64T5L low-pressure lamps stacked in a configuration of three lamps per cleaning assembly with total lamp power of 1235 W (65 W per lamp). The lamps were oriented parallel to flow and each lamp had one power setting (100% lamp output). The unit included one UV irradiance sensor that measured the output from one of the nineteen lamps and could be verified against a calibrated reference sensor.

**Figure 1. Installation of Trojan Technologies UVSwift 4L12 Unit**

A flow rate of 695 gpm and a UV lamp power setting of 81% was used for the Trojan UVSwift Model 4L12 unit. A flow rate of 350 gpm and a 100% lamp power setting was used for the Atlantic Megatron M250 unit. Any residual chlorine disinfectant was quenched with sodium metabisulfite prior to passage through the UV units. A set of positive control samples and concurrent collimated beam testing was also performed.

The results of the challenge studies for the two UV systems are presented in Figure 4 and Figure 5. The microbial inactivation observed during the challenge tests ranged from 2.1 to 3.0 logs for the Trojan UVSwift Model 4L12 and 1.7 to 2.1 logs for the Atlantic Megatron M250 unit. No inactivation was observed during the positive control tests with the lamps off.

**Figure 4. Virus Seeding Results for Trojan UVSwift Model 4L12 (695 gpm).**

**Figure 5. Virus Seeding Results for Atlantic Megatron M250 (350 gpm).**

The Trojan Technologies UVSwift Model 4L12 power usage was 0.32 kwh/1000 gal at a flow rate of 400 gpm and a power setting of 81% for the. Power usage for the Atlantic Megatron M250 unit was 0.053 kwh/1000 gal at a flow rate of 350 gpm and 100% lamp power. Sensor calibration data for both units ranged from approximately 2% to 11% over the testing period.
Table 1. Otay Lake Feed Water Quality Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Trojan Range</th>
<th>Atlantic Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>mg/L as CaCO₃</td>
<td>127 – 168</td>
<td>111 – 137</td>
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<tr>
<td>Total Hardness</td>
<td>g/L as CaCO₃</td>
<td>196 – 227</td>
<td>212 – 259</td>
</tr>
<tr>
<td>Iron</td>
<td>µg/L</td>
<td>50 – 85</td>
<td>50 – 57</td>
</tr>
<tr>
<td>Manganese</td>
<td>g/L</td>
<td>0.91 – 9.3</td>
<td>0.5 – 1.8</td>
</tr>
<tr>
<td>Nitrate</td>
<td>mg/L</td>
<td>0.2 – 0.57</td>
<td>0.4 – 0.9</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/L</td>
<td>2.96 – 5.11</td>
<td>2.3 – 4.6</td>
</tr>
<tr>
<td>Color</td>
<td>PtCU</td>
<td>2 – 5</td>
<td>1 – 3</td>
</tr>
<tr>
<td>UV254</td>
<td>l/cm</td>
<td>0.034 – 0.083</td>
<td>0.042 – 0.068</td>
</tr>
<tr>
<td>pH</td>
<td>std. Unit</td>
<td>7.3 – 8.9</td>
<td>7.5 – 8.6</td>
</tr>
<tr>
<td>Desktop Turbidity</td>
<td>NTU</td>
<td>0.10 – 0.20</td>
<td>0.10 – 0.10</td>
</tr>
<tr>
<td>Temperature</td>
<td>C</td>
<td>20.3 – 24.7</td>
<td>17.3 – 20.5</td>
</tr>
<tr>
<td>Free Chlorine</td>
<td>mg/L</td>
<td>0.04 – 1.4</td>
<td>0.07 – 3.20</td>
</tr>
<tr>
<td>Total Chlorine</td>
<td>mg/L</td>
<td>1.5 – 3.0</td>
<td>1.56 – 3.34</td>
</tr>
</tbody>
</table>

*Figure 3. Treatment Process Schematic (Shown for the Atlantic Megatron M250 identical for the Trojan UVSwift Model 4L12).*

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Investigates the effectiveness of ozone, potassium permanganate, chlorine, chlorine dioxide, and ultraviolet radiation (UV) on inactivation of Cryptosporidium. Also investigates the use of combinations of disinfectants such as ozone-UV and ozone with hydrogen peroxide. Research partner: USEPA. Catalog No. 90734 Member Price: $10.00 Non-member Price: $15.00

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INACTIVATION AND POTENTIAL REPAIR OF CRYPTOSPORIDIUM PARVUM FOLLOWING LOW- AND MEDIUM-PRESSURE ULTRAVIOLET IRRADIATION,
J. L. Zimmer, R. M. Slawson, and P. M. Huck
a. Department of Biology, University of Waterloo, Waterloo, Ont., Canada, N2L 3G1; b. Department of Civil Engineering, NSERC Chair in Water Treatment, University of Waterloo, Waterloo, Ont., Canada, N2L 3G1. Water Research, 37(14):3517-3523, August 2003

This study investigated the level of inactivation and the potential for Cryptosporidium parvum to repair following low doses (1 and 3 mJ/cm²) of ultraviolet (UV) irradiation from both low- and medium-pressure UV lamps. Cryptosporidium parvum oocysts suspended in phosphate buffered saline were exposed to UV using a bench-scale collimated beam apparatus. Oocyst suspensions were incubated at 5°C or 25°C under light and dark conditions up to 120 h (5 days) following exposure to UV irradiation, to examine photoreactivation and dark repair potential, respectively. Cryptosporidium parvum infectivity was determined throughout the incubation period using an HCT-8 cell culture and an antibody staining procedure for detection.

No detectable evidence of repair was observed after incubation under light or dark conditions following either LP or MP UV lamp irradiation.

PHOTOCATALYTIC DEGRADATION OF E. COLIFORM IN WATER
Darren Delai Sun Joo Hwa Tay and Koh Min Tan

This study aims to further investigate the total mineralization of the bacteria to the extent of death and cell-mass inactivation using a TiO₂-Fe₂O₃ membrane photocatalytic oxidation reactor. Experimental results clearly indicated that dissolved oxygen (DO), hydraulic retention time (HRT) and concentration of the model bacteria (Escherichia coli) affected the removal efficiency. It was found that the ultimate removal efficiency was 99% at DO level of 21.34 mg/L, HRT at 60 s and high concentration of E. coli at 10⁷ CFU/mL. The morphologic studies also showed that E. coli could be further mineralized into CO₂ and H₂O. Dissolved organic carbon, pH and gas chromatograph analysis had justified most importantly the evolution of CO₂. Experimental results revealed that the photomineralization rate of E. coli followed pseudo-first-order kinetics by the role of DO. The derived empirical models were found consistent with the proposed reaction pathways of a combined UV breakdown on mass cell and a dual-site Langmuir–Hinshelwood mechanism where
the rate-controlling step is the surface interaction between the adsorbed cleavage bacterial cells and hydroxyl radicals.

ZERO-VALENT IRON REDUCTION OF NITRATE IN THE PRESENCE OF ULTRAVIOLET LIGHT, ORGANIC MATTER AND HYDROGEN PEROXIDE

Chih-Hsiang Liao, Shyh-Fang Kang and Yu-Wei Hsu

This paper describes the use of metallic iron (Fe0) powder for nitrate removal in a well-mixed batch reactor. Important variables explored include Fe0 dosage (1-3 g/L), UV light intensity (64-128 W), and the presence of propanol (20 mg/L as DOC) and H2O2 (100-200 mg/L). Accumulation of ferrous ions released from the Fe0 surface can be expressed by an S-curve, which involves lag growth phase, exponential phase, rate-declining phase, and saturation phase. The removal of nitrate increases with increasing Fe0 dosage; however, the removal makes no difference as the Fe0 dosage is greater than 2 g/L. UV irradiation retards the dissolution of ferrous ion and the removal of nitrate. The species of propanol, which has a functional group of -OH, plays a role of organic inhibitor for Fe0 corrosion. The presence of H2O2 appears to inactivate all reactions as the Fe0 of 10 m was used; the final H2O2 remains intact throughout the entire reaction period, and there were no removal of nitrate and no dissolution of ferrous ion. Surprisingly, with the use of a larger Fe0 particle size of 150 m, the H2O2 was seen to decompose rapidly through Fenton reaction. Nevertheless, the rate of ferrous accumulation or nitrate removal is slow.

PHOTOCATALYTIC DEGRADATION OF AQUEOUS POLLUTANTS USING SILICA-MODIFIED TiO2

Muhammad Shariq Vohra and Keiichi Tanaka
(Department of Applied Chemistry, Faculty of Engineering, Oita University, 700 Dannoharu, Oita 870-1192, Japan). Water Research 37(16): 3992-3996, September 2003.

Photocatalytic degradation (PCD) of several aqueous pollutants was investigated using a porous silica-coated titanium dioxide (SiO2-TiO2) photocatalyst. Several cationic, neutral and anionic pollutants were tested. The results indicate that modifying the surface properties of TiO2 using silica significantly enhances the PCD rate of the cationic pollutants. The rate enhancement decreased with an increase in substrate concentration, especially for the quaternary amines, and was attributed to the decrease in initial adsorption. However, no significant rate-increase resulted for acetate and phenol. Results suggest that the increased presence of cationic pollutants at the catalyst surface caused the rate enhancement.
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Special Issue of IUVA News Coming

Issue #4 of 2003 is being put together as a Special Issue – reviewing the impacts of the newly proposed U.S. EPA drinking water regulations: the LT2ESWTR (Long Term 2 Enhanced Surface Water Treatment Rule) and the Stage 2 D/DBP (Disinfectants and Disinfection By-Products) Rule that are accompanied by a 475-page UV Guidance Manual, under development by experts in the UV field for the past 5-7 years. These rules, to be finalized next year by the EPA, will have a dramatic impact on the future of UV technologies in drinking water treatment, initially in the USA over the next few years, but also around the world soon thereafter.

It is the intention of your Editors to devote issue #4 (2003) of the IUVA News Print Version to a summary and discussion of these new EPA drinking water regulations and their impacts on UV technologies. At present, we envision a document of 40-48 pages, with Christine Cotton as Special Editor. We solicit your advertising for this special issue, and plan to print extra copies for sale as reference material in the years to come.
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