

# Lessons Learned from UV System Performance Audits for Reuse Applications

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## Abstract

Many installed UV systems operate inefficiently over time, which increases operation and maintenance (O&M) costs and can lead to microbial permit violations. A WaterReuse Research Foundation (WRRF) project titled “UV Disinfection Knowledgebase for Reuse Applications” is evaluating these issues. The objectives of this project were to benchmark the performance of UV systems used in reuse applications, develop recommendations for UV implementation for non- and direct potable reuse, and develop troubleshooting tools that utilities can use to quantify and optimize UV system operation. Lessons learned from conversations with operators along with data collected during the UV system performance audits provides good recommendations for better UV implementation.

**Keywords:** UV Disinfection, Water Reuse, Optimization, Audits, Lessons Learned

## Introduction

Ultraviolet (UV) light is used for reuse water disinfection across the United States and throughout the world. The design, validation and operation of reuse UV systems often are conducted in accordance with National Water Research Institute (NWRI) UV Guidelines. In practice, many UV systems operate inefficiently over time as a result of sleeve fouling, accelerated lamp aging, and overdosing arising from overly conservative design. This can increase operation and maintenance (O&M) costs and can lead to microbial permit violations. A WaterReuse Research Foundation project titled “UV Disinfection Knowledgebase for Reuse Applications” is evaluating these issues.

The objectives of this project are to benchmark the performance of UV systems used in reuse applications, develop recommendations for UV implementation for non- and direct potable reuse, and develop troubleshooting tools that utilities can use to quantify and optimize UV system operation.

## Methodology

The first part of this project involved conducting UV system performance audits at participating UV facilities across North America. The approach for the UV audits was based on techniques developed through previous Water Research Foundation projects and successfully applied with previous reuse

UV systems. Each audit included a review of UV system design and performance data, a visual inspection of the UV system, and measurements of lamp aging, sleeve fouling and UV sensor fouling using a custom optics bench.

Measurements of the indicator microorganism UV dose response using a collimated beam apparatus and log inactivation through the reactor were used to determine the UV dose delivery of the reactor and any potential short-circuiting or bypass of water.

The UV dose-monitoring algorithm programmed into the UV system PLC, which is typically developed during validation, was evaluated to confirm proper operation. Measurements of the power consumption and accuracy checks of UV sensor (when applicable) and UV transmittance (UVT) monitors also were conducted.

The actual power consumption was measured using a Fluke 434 power quality analyzer. The readouts of the online UVT monitors were compared to UVTs measured by a portable RealTech monitor that was calibrated using distilled water prior to measurements.

## Results

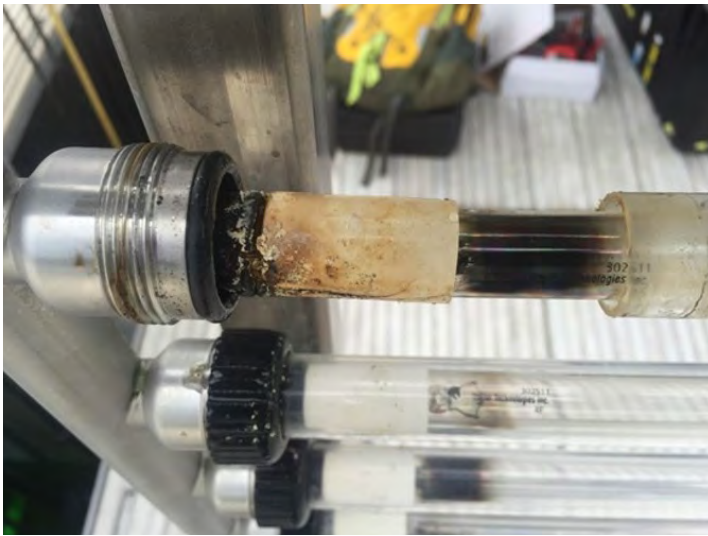
UV audits were performed on a mix of medium pressure (MP), low-pressure high-output (LPHO) and low-pressure (LP) UV systems from several different vendors.

## Visual inspection

An initial visual inspection of each UV system was conducted to evaluate the physical condition of the UV system components, sleeve fouling and lamp aging, the wiper mechanisms and the degree to which algal growth may be interfering with system performance.

Often the visual inspection confirmed comments provided by the operators on the issues causing difficulties with system maintenance.

Algal growth was seen at many of the locations but did not seem to interfere with the UV system performance. Lamp end darkening and corrosion were seen at several locations (Figure 1). This can occur when water gets in the sleeves during a lamp or sleeve change and can cause lamp failures.



**Figure 1.** Lamp end darkening and corrosion

One location had significant damage of wiper seals that exposed the spring used to maintain pressure on the sleeve (Figure 2). The operators reported that during operation, the wiper cleaning fluid may have leaked out, causing wear of the wiper seal and the spring breaking through. Once the wiper seals had worn through, the exposed spring scratched the quartz sleeve, and in some cases, the exposed spring grabbed the quartz sleeve, pulling it out of its attachment point at the end of the lamp module, allowing water to enter the sleeve and causing lamp failures.



**Figure 2.** Broken wiper seals with exposed springs

At a few locations there were issues with lamp and sensor connections, as well as clearance issues, when removing modules from the channel that were noted by the operators. Figure 3 shows that the electrical connections to the reactors had some open spaces that allowed for possible misalignment when reconnecting. This led to some mechanical failures of the plug that the vendor had to address. Figure 4 (on page 6) shows some clearance issues encountered when trying to remove modules from the channel for maintenance. In these systems, the outside modules could not be removed without also removing the adjacent modules because part of the bank frame was in the way.

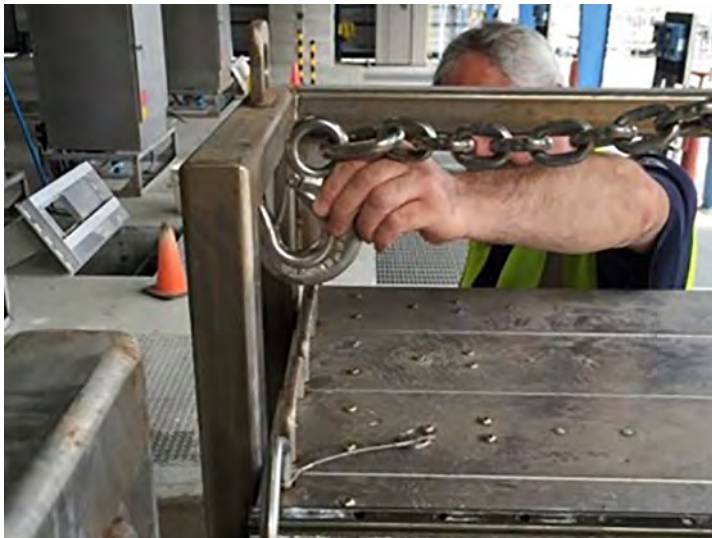


**Figure 3.** Loose lamp and sensor cable connections

**Lamp aging and sleeve fouling**

Sleeves from one to two modules were used for sleeve fouling measurements. These measurements provided a snapshot of the fouling taking place at each location. The sleeve fouling factors were measured using a customized optics bench that consisted of a low-pressure mercury lamp source contained within an aluminum box (Figure 5), a radiometer (International Light IL 1700) to measure the light from the lamp source, and supports to allow precise placement of a quartz sleeve and lamp in the light path from source to radiometer. This device allowed direct measurement of the transmittance of UV light at 254 nm wavelength through clean and fouled sleeves and new and aged UV lamps.

The degree of UV absorbance of the quartz sleeve and lamp envelopes has been shown in prior research to correlate with



**Figure 4.** Clearance issues when removing modules

sleeve fouling and lamp aging (Heath et al., 2013). The UV transmittance of the sleeve and lamp was calculated using:

$$SFF, LAF = \sqrt{\frac{I_1}{I_2}} \quad [1]$$

where SFF is the sleeve fouling factor, LAF is the lamp aging factor,  $I_1$  is the UV intensity measured through an aged lamp or fouled sleeve and  $I_2$  is the UV intensity measured with a new and clean sleeve or lamp. The square root function accounts for the fact that the UV light from the optics bench source passes the two layers of quartz in the sleeve or lamp. A SFF or LAF of 0.80 means that 20 percent of the UV light emitted by the lamps at 254 nm is absorbed due to fouling

of the external and internal surfaces of the quartz sleeves or solarization of the lamp quartz envelope by the mercury contained within an operating UV lamp.



**Figure 5.** Custom optic bench for direct measurement of sleeve transmittance and fouling

Table 1 gives the sleeve fouling measurements of systems at 10 locations along with the cleaning mechanism for each system. A typical sleeve fouling factor, such as the fouling factor used by the 2012 NWRI guidelines, is 80 percent. Most systems have values within an 85 to 95 percent range. The MP systems showed the greatest overall range of fouling of 60-98 percent. This typically arises from the accelerated rates of fouling resulting from the excessive heating of the quartz from the high temperature MP lamps.

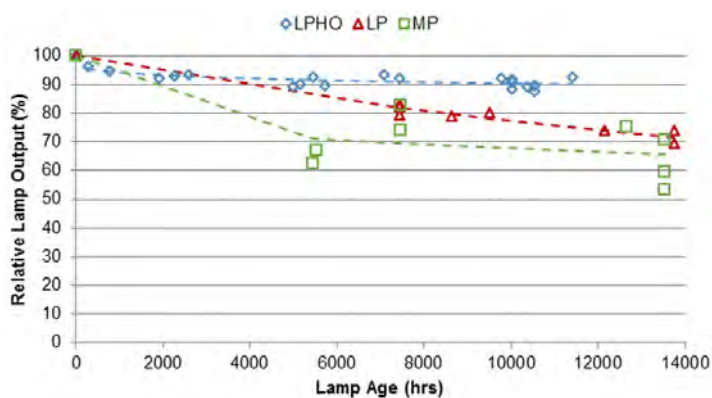
The LPHO systems generally had fouling within both the vendor and NWRI criteria. However, there were two systems that showed greater sleeve fouling of 61-70 percent and 5-88 percent. The LP system had negligible sleeve fouling in range of 97-100 percent.

**Table 1.** Sleeve fouling measurements

Reactor type	Sleeve fouling range (%)	Sleeve cleaning mechanism
MP	60-93	Mechanical
MP	75-98	Mechanical
LHPO	88-102	Mechanical
LHPO	61-70	Mechanical
LHPO	89-100	Mechanical
LHPO	94-100	Mech./periodic acid bath
LHPO	97-100	Mech./periodic acid bath
LHPO	5-88	Automatic wipers
LHPO	84-93	Mech./periodic acid bath
LP	97-100	Acid bath
Default NWRI	80	-
Vendor criteria	85-95	-

Lamp aging factors were measured using the same approach used for determining sleeve fouling factors. Lamps with a range of operating hours were used to develop the lamp aging curves provided in Figure 6.

The lamp aging curve shown for the LPHO lamp was consistent for a variety of systems and vendors. The curve starts out at 100 percent for new lamps followed by a steep drop in relative lamp output to around 90 percent at which point it levels off until the end of lamp life around 12,000 hours. The MP lamp aging curve shows a sharper decrease in the relative lamp output in the first 5,000 hour before leveling off around 65 percent. The LP lamp aging curve shows a steady decrease in the relative lamp output down to 70 percent after 14,000 hours.



**Figure 6.** Lamp aging curves for LPHO UV systems

### Power and UVT measurements

Power measurements were recorded to confirm that the UV systems were operating at the intended power setting. Only one location did not show the expected power consumption and was found to only be able to operate at 68 percent power regardless of PLC setting. After working with the operators and UV vendor, it was determined there was a bad resistor that prevented the system controller from operating over the full range of power.

UVT measurements using the handheld RealTech unit showed that several UV systems had large differences, sometimes up to 12 percent, between readings from the online UVT monitor and the measured UVT of the water. These differences can cause significant dose monitoring errors. If, for example, the online UVT monitor is reading higher than the measured UVT than the system could be underdosing, which could lead to permit violations. If the online UVT monitor is reading lower than the measured UVT than the system could be overdosing, which means the systems is not operating as efficiently as it could be.

### UV dose monitoring algorithm

Most UV systems are equipped with a PLC that calculates the UV dose delivered by the UV reactors. UV systems can operate in automatic mode turning on and off banks of lamps and adjusting the lamp ballast power setting so the UV system meets a UV dose target without significant overdosing. Understanding the UV dose monitoring and control algorithm used by the PLC is key toward understanding the overall UV system performance. The details of the UV dose-monitoring algorithm used by a given UV system PLC typically are not described in the UV system documentation provided by the manufacturer. Hence, data was collected during the site visit to evaluate the UV dose-monitoring algorithm. The UV system was operated with various entered values of UVT, lamp power setting, flow rate, and lamp aging and sleeve fouling factors, and the UV dose (RED) reported by the system PLC was recorded.

While most of the UV systems observed for this study had UV sensors to monitor the UV output, not all of the systems utilized the UV sensor signal in the UV dose monitoring algorithm. The algorithm instead assumed a lamp output based on a lamp aging study and an assumed sleeve fouling factor. The use of assumed lamp aging and sleeve fouling factor as opposed to measured lamp output could lead to an over estimated dose when lamp aging and fouling exceed assumptions.

### Microbial measurements

To quantify the performance of the UV system, samples were collected upstream and downstream of one operating bank in the UV system. Inactivation of indicator organisms through a single bank can be compared to the measured UV dose response generated by collimated beam testing to demonstrate the actual UV dose delivery in the channel. This then can be compared to the delivered dose calculated by the UV system control algorithm.

An additional focus of this sampling was to determine if there was any short circuiting of untreated water through the UV system or even complete bypass of UV system. In order to evaluate this, samples were collected at the UV system compliance point and at a point further downstream, such as at the flow control weir where greater mixing likely occurred. To increase the detection limit of microbial indicators beyond the normal 1 CFU/100 mL, larger sample volumes were collected, up to 500 mL, to allow a detection limit of 0.2 CFU/100 mL.

At most plants, indicator organism concentrations were below detection at both the compliance point and the downstream location. However, a few facilities showed some possible bypass concerns either through leaks in gates or valves, or from bypass through the channel's drains.

### Lessons learned

Based on the data collected during the UV performance audits, UV systems that do not utilize UV sensors to monitor the output of UV lamps but instead rely on idealized lamp aging and fouling assumptions, could be significantly underdosing. Therefore, it is important to use realistic lamp aging and fouling estimates or, alternatively, use a UV sensor-based validated dose monitoring system that accounts for actual lamp output. Some of the issues found with the power and UVT measurements show that more attention needs to be paid to dose control programming during startup of the UV system, and online UVT monitors should be routinely calibrated. It is also important to check for open drains or leaks that could cause untreated wastewater to bypass the UV system.

Some of the biggest lessons learned from this study came from the operators. When dealing with the module and equip-

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ment design issues, operators are finding solutions that work best for their location. Some examples of modifications made at some of the locations visited include:

- A closed building. The original design of the UV building had only a roof, but they were having issues with birds nesting in the roof. Walls were later added to help keep the system cleaner.
- The UVT monitor was originally sampling from a dead zone in the channel. It was moved to sample at the inlet to the channel to give better readings of the water quality.
- A spring-loaded inlet valve was added that automatically shuts down (even with a power failure) if there is a problem with the UV system not meeting the required dose.
- To help with maintenance, most operators would prefer multiple channels and want easier access to ballast and lamps.

At several locations, operators reported that the UV systems required much more maintenance than anticipated. These same operators reported more issues with their UV systems and were more likely to have a negative view of UV, preferring to use chlorine instead. At the locations where operators had positive views of UV technology, the UV systems tended to perform better. The operators viewed the maintenance as something that needed to be done to have a well running system. Therefore, it is important to have clear communication about the maintenance needed to have a well running UV system. ■

### References

Heath, M., Wright, H., Schmalwieser, A.W. 2013, UV Lamp Aging is Predicted by Direct Measurement of UV Transmittance. Paper presented at International Ultraviolet Association Annual Conference, Las Vegas, NV, November 2013.



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