Quartz Lamp Sleeve Fouling and Cleaning System Evaluation at the Albany, New York Loudonville UV Treatment Facility

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ABSTRACT

Experiments utilizing a medium pressure UV disinfection reactor at the Loudonville UV Treatment Facility (Albany, New York) were conducted to assess the effects of an interruption to sleeve wiping. The surface water source used had relatively low concentrations of the dissolved minerals sometimes associated with problematic sleeve fouling. Effects of sleeve wiping interruption were assessed by monitoring the temporal distribution of UV dose and by post-experimental sleeve analysis. UV transmittance of clean and fouled sleeves was characterized, and chemical analysis of lamp sleeves was performed to quantify metals content on sleeve surfaces. Sleeve UVT decreased from approximately 92 % to 61% (relative to air) after four weeks. During this time the average reported UV dose during a set of common operating conditions decreased by 9.5%. For this location, over-cleaning of the quartz lamp sleeves (and associated sleeve damage) may be a greater threat to consistent sleeve UVT than acute inorganic fouling.

Keywords: UV disinfection, sleeve fouling

INTRODUCTION

The fouling materials that sometimes form on lamp sleeve surfaces in potable water disinfection reactors absorb ultraviolet (UV) light, and thereby interfere with the disinfection process. This can lead to decreases in the antimicrobial efficacy of a UV reactor, and therefore automated sleeve cleaning systems are often utilized. Sleeve cleaning systems are reported to be effective at removing foulants and in keeping sleeve UV transmittance high (Oliver 2003), but long-term use can cause scratches on lamp sleeve surfaces that favor the formation of permanent foulants (Peng et al., 2005). Thus, while there is merit in utilizing sleeve cleaning systems to ensure disinfection process performance, there is also reason to limit the frequency of sleeve cleaning operations in order to reduce sleeve damage and permanent fouling.

The experiments described herein were undertaken to benchmark fouling behavior in a medium pressure drinking water UV disinfection reactor treating a surface water source with a relatively low concentration of dissolved metals. By monitoring reductions in the reported UV dose, and by post-experimental analyses of foulant chemistry and lamp sleeve transmittance, the rate of performance degradation due to fouling was characterized.

METHODS AND MATERIALS

Experiments were conducted at a full-scale installation using a UV Swift medium pressure disinfection reactor manufactured by Trojan Technologies Inc. (London, Ontario, Canada). During a baseline operational period, the automated sleeve cleaning system was enabled to permit wiping of the quartz lamp sleeve exterior every 24 h. The cleaning system in this reactor utilizes a combination of abrasion and chemical application. During the experimental operational period, automated sleeve cleaning was disabled to allow accumulation of fouling on the sleeve surface and subsequent assessment of performance effects and post-experimental physical and chemical analyses.

Automated data-logging recorded the flow rate, reactor input power, and a calculation of the UV dose delivered to the water. Since flow rate and reactor input power varied over time, and since reactor irradiance measurements were not directly available, a subset of the logged reactor UV dose calculations was utilized as a temporally-distributed indicator of the effects of sleeve fouling. During the fouling experiment, the flow rate through the reactor varied from 0 to 7 million gallons per day (mgd), and the input power varied among settings of 0%, 60%, 80%, and 100%. The recorded UV dose dataset was screened (60% power and flow of 2.4 to 2.6 mgd) to yield a subset with common operating conditions.

During times when the reactor was receiving the same input power and treating the same flow rate, it was hypothesized that in the absence of fouling, the UV dose should be constant over time. Decay in the output of the UV lamps could also influence the UV dose. However, given the relatively short experiment duration, it is reasonable to assume that the effects of lamp output decay were minimal.

Lamp sleeve ultraviolet transmittance (UVT) measurements were performed using a fiber optic spectrophotometer coupled with a pulsed xenon radiation source. By sliding a fouled lamp sleeve through a track-mounted scanning assembly (Wait and Blachley 2005), the spatial distribution of the UVT was characterized. Four lamp sleeves were removed from the reactor for UVT analysis after two weeks of operation, and four more sleeves were removed after four weeks.

Chemical analysis included acid digestion of fouled lamp sleeve exteriors followed by Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES) quantification of soluble metals. Fouled lamp sleeves were immersed in a fixed volume of a 0.5 M HCl and 0.005 disodium EDTA, and the solution was analyzed according to the EPA method 200.7. Resulting metals concentrations were converted to a metals surface loading (mmol/m^2) by considering atomic weight, surface area digested, and volume of acid solution utilized.

Water samples were quantified by the EPA method 200.7 for metals, Standard Methods 4110 for anions (APHA, 2005), and Standard Methods 2320 for alkalinity. A profile of the water used in the experiments is provided in Table 1.

Table 1. ***Results of water chemistry analysis for the water used during experimentation.***

Parameter	Water Sample Units	Water Sample Concentration	Foulant Uptake Ratio (unitless)
Al	mg/L	0.08	12.01
Ca	mg/L	20.33	0.11
Fe	m /L	0.020	1369
K	mg/L	< 2.00	-
Mg	mg/L	2.270	0.00
Mn	mg/L	< 0.005	> 238[a]
Na	mg/L	17.9	-
Zn	mg/L	< 0.001	> 270[a]
Chloride	mg/L	32.73	-
Phosphate	mg/L	< 0.1	-
Sulfate	mg/L	9.34	-
pH		7.3	-
Temperature	°C	15	-
Alkalinity	mg/L $CaCO_3$	45	-

a.* *Detection limit used for water concentrations

Visual MINTEQ (Gustafsson 2005), was used to characterize the water mineral saturation indices during the experiments to identify possible dissolved mineral contributors to the observed fouling.

RESULTS

Fouling occurred during the period of sleeve cleaning system interruption, as evidenced by changes of reported UV dose delivery over time, changes in lamp sleeve UVT, and analysis of accumulated foulant material. Figure 1 shows the results of the chemical analysis of the lamp sleeve exterior.

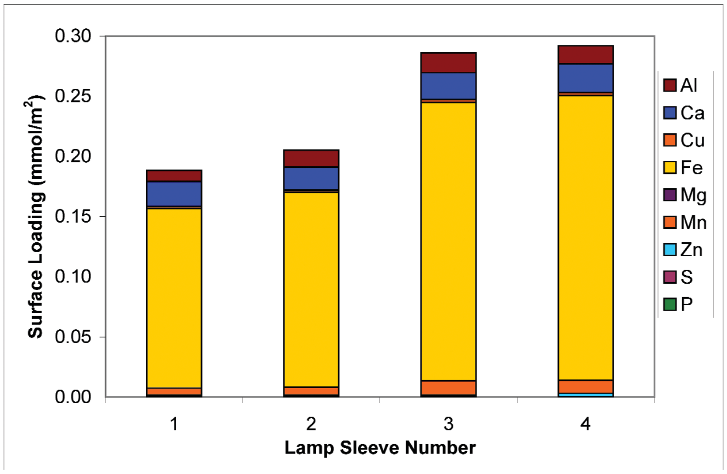

Figure 1. ***Results of lamp sleeve foulant chemical analysis at the conclusion of the four week experiment period, showing iron as the predominant metal component.***

By plotting the UV dose versus time for a set of common operating conditions, Figure 2 shows that the linear regression curve fit to the experimental data is relatively flat, when sleeve cleaning is active, with a negative slope of 0.04 mJ/cm^2 per day. However, with the sleeve cleaning system disabled the average UV dose decrease is 1.07 mJ/cm^2 per day, indicating reduced reactor performance during this period of enhanced fouling accumulation.

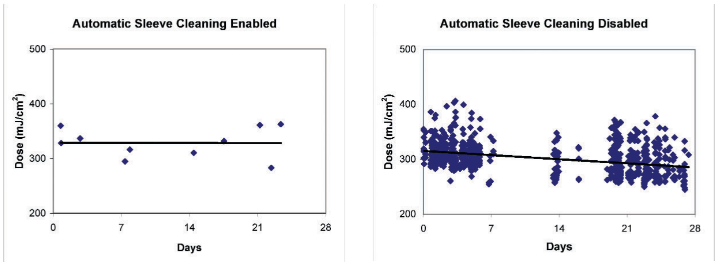

Figure 2. ***Measurements of the average UV dose with reactor at 60% power and plant flow 2.4 - 2.6 mgd. For the period where sleeve wiping was enabled (left), linear regression indicates a UV dose decrease of 0.04 mJ/cm^2 per day, compared to a decrease of 1.07 mJ/cm^2 per day with sleeve wiping disabled (right).***

Prior to chemical analysis of sleeve foulant materials, the sleeves were scanned at 2-cm increments to quantify their spatially distributed change in UV transmittance. As shown in Figure 3, after two weeks of operation, the transmittance of sleeves relative to air decreased from approximately 92% prior to experimentation (when the sleeves were clean)[1] to spatially averaged values of approximately 72%, 71%, 73% and 71% for the four sleeves. The sleeves experiencing four weeks of fouling yielded average transmittances of approximately 60%, 58%, 61%, and 66%.

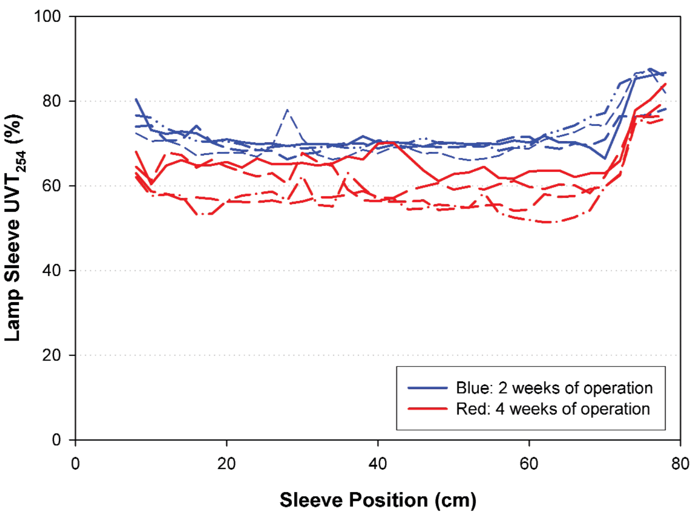

Figure 3. *Lamp sleeve transmittance scanning.*

Discussion

These experiments illustrate that even at locations where acute fouling is not problematic and accumulation of foulant materials is unlikely to be measurable over the course of a few days, fouling still does occur and can be quantified over the course of the longer term. This points to the importance of benchmarking fouling behavior at locations where UV disinfection is to be used and the need for periodic sleeve cleaning.

The water utilized in these experiments has low concentrations of iron and calcium relative to the quantities typically associated with problematic short-term sleeve fouling. (Bratz and Hedges 2001; Job et al. 1995; Oliver 2003). The gradual longer-term decrease in UV dose shown in Figure 2 for disabled sleeve cleaning conforms to expectations, with the 9.5% decrease in average UV dose indicating that even with the automated sleeve cleaning system disabled, fouling was slower and less severe than at locations with mineral-rich groundwater.

An evaluation of the chemical composition of the water utilized in the experiments with respect to mineral saturation indices suggests that in spite of relatively low concentrations of most metals, several iron-containing minerals (*e.g.*, hematite, magnetite, and maghemite) exist in solution at a positive saturation index. While not accounting for the rate of formation of the minerals identified, this approach does indicate whether supersaturation exists from a thermodynamic standpoint, and illustrates the pathway by which foulant formation may have occurred. Calcium-containing minerals were computed to be sub-saturated, and this conforms to observations of the relatively small contribution of calcium to the overall foulant composition (see Figure 1).

The net foulant surface loadings that were detected were between 0.19 and 0.29 mmol/m^2 for the fouled sleeves digested at the end of the experiment. Assuming zero-order fouling kinetics, as has been observed in several settings, (Lin et al. 1999; Wait 2005), this translates to an accumulation rate of 0.0068 – 0.0104 mmol/m^2 per day.

This rate of accumulation during a period of disabling the automated sleeve cleaning system is low relative to rates of foulant accumulation that can occur with mineral-rich ground waters undergoing oxidation processes. In these acute fouling cases, surface loading rates on the order of 2 mmol/m^2 per day have been observed (Wait 2005), and in cases such as these, reactor irradiance can decrease by as much as 80% in a single day. By comparison, the relatively minor fouling that occurred with the low-hardness, already-oxidized, surface water utilized in these experiments is less threatening to the continued effective operation of a disinfection reactor. Rather, the long-term accumulation of permanent foulants – which in some cases have been reported to reduce UVT by as much as 72% depending on the cleaning method utilized (Peng et al. 2005) – may be the greater risk.

Although containing fewer data points than the experimental dataset, the baseline UV dose dataset shown in Figure 2 (page 12, left) illustrates a trend that is stable over time. The relatively flat slope of the linear regression trend line shown in Figure 2 (page 12, left) implies that with sleeve wiping enabled, the UV dose did not exhibit a significant decreasing trend over time. The long-term stability of the UV irradiance in reactors utilizing sleeve cleaning systems has been previously reported (Oliver 2003).

A stable reported dose when cleaning is enabled is contrasted by a gradual decrease when cleaning is disabled, as shown in Figure 2 (page 12, right), where the average UV dose reported during the previously-outlined screening conditions decreased by 9.5%. Although there is some variance in the data, possibly due to fluctuations in lamp and water temperature, the overall negative trend illustrates the effect of sleeve fouling on reactor performance.

Comparing the relative abundance of a metal in the foulant matrix to its relative abundance in solution is one way to evaluate its propensity to participate in fouling. By dividing the mole fraction of each metal in the foulant by its respective mole fraction in water, an uptake ratio was

[1] 92% transmittance corresponds to zero absorption in the quartz, since 4% of the incident UV light is reflected from the front and the back surfaces.

computed. As shown in Table 1, iron had the highest relative ratio (1369) of quantity in foulant to quantity in solution. The participation of iron in fouling processes has previously been identified for fouling of wastewater disinfection systems utilizing low-pressure UV lamps (Lin et al. 1999c; Sheriff and Gehr 2001). Calcium, which is an important contributor to fouling at many sites utilizing ground water, was less active, accounting for 84% of the total moles of polyvalent metals in solution, but only 9% on the fouled sleeve, leading to an uptake ratio of 0.11.

CONCLUSIONS

These experiments benchmark the rate of fouling for a surface water source with relatively low concentrations of calcium, iron, and other foulant contributors that can signal the potential for acute fouling of quartz lamp sleeves that are used in UV disinfection reactors. In spite of the low concentration of dissolved metals, fouling was observed via reductions in the UV dose during the experiment where sleeve cleaning was disabled, and after the experiment via chemical analysis of the sleeve exteriors and analyses of UV transmittance.

While some UV installations are likely to experience rapid, problematic sleeve fouling if sleeve cleaning systems are not in place, these experiments illustrate the performance of a reactor treating a surface water producing only gradual fouling when sleeve cleaning was disabled. The 9.5% reduction in reported UV dose during 28 days of sleeve cleaning interruption represents a change in performance too large to be neglected, but too small to justify the same frequent, vigorous cleaning often used at locations with problematic fouling. In order to balance the need for adequate foulant removal with sleeve surface damage prevention, it is recommended that sleeve cleaning frequency be based on location-specific evaluations of fouling rate and changes in reactor irradiance.

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