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TREATMENT
Blacklights Battle Nitrification

DISTRIBUTION
Pump Maintenance Ensures Efficient Operation

CONTAMINANTS
Reduce Vinyl Chloride Levels

SUSTAINABLE SYSTEMS
Redefining the US Infrastructure Challenge

VOLUME 36, NO. 2 FEBRUARY 2010

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The Los Angeles Department of Water and Power is experimenting with near-ultraviolet (UVA) radiation to mitigate nitrification. Water is relatively transparent to UVA radiation, which can inactivate nitrifying bacteria at low intensities. BY BRIAN WHITE AND MARTIN ADAMS

BATTLING NITRIFICATION WITH BLACKLIGHTS

THE LOS ANGELES DEPARTMENT of Water and Power suspended a bank of fluorescent blacklights in the headspace of Mount Washington Tank 2 in July 2009. The idea was to test whether standard overhead light fixtures could supply enough near-ultraviolet (UVA) radiation to prevent nitrification onset in covered storage facilities containing chloraminated water. The utility undertook a full-scale tank retrofit to explore this practical application for combating nitrification.

LADWP is currently expanding its replacement of chlorine with chloramines as the city's secondary disinfectant. Although chloramines form fewer disinfection by-products and eliminate chlorinous odor, they encourage nitrification in covered storage facilities. The nitrification process begins with routine decomposition of chloramine disinfectant, which consists of chlorine and ammonia. As ammonia and chlorine separate, resulting ammonia becomes a source of energy for ammonia oxidizing bacteria, such as *Nitrosomonas*, which convert ammonia to nitrite. Nitrite-oxidizing bacteria, including *Nitrobacter*, complete the process by converting nitrite to nitrate. Both *Nitrosomonas* and *Nitrobacter* are sensitive to low-intensity UVA radiation.

Nitrification can rapidly deplete tank chloramines, and maintaining tank residuals with unforeseeable spot treatments is labor intensive and contrary to maintaining low disinfection by-products. To prevent nitrification, LADWP is experimenting with the application of UVA radiation.

PHOTOGRAPH: ART MOCHIZUKI, LADWP

LADWP undertook a full-scale tank retrofit to determine whether standard overhead light fixtures could supply enough UVA radiation to help prevent nitrification in covered storage facilities containing chloraminated water. The results have been encouraging.

PILOT PROJECT

The pilot project was conducted at full-scale at Mount Washington Tank 2 because the optical, chemical, biological, and operational complexities of a fill-and-draw tank couldn't be duplicated in a laboratory. In addition, sufficient information to devise realistic lighting specifications was already available in scientific literature. The literature-derived minimum UVA intensity assumed 24 hr of continuous exposure across the bottom of a full tank. This conservative approach assured overexposure of the overlying water column.

Mount Washington Tank 2 was selected as the test bed for several reasons:

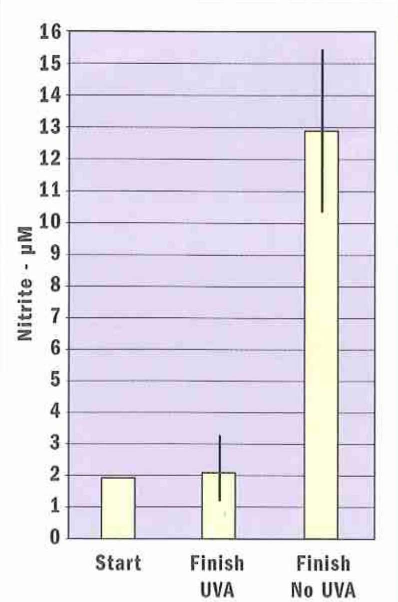
- The tank has distributed chloraminated water to a small pressure zone near downtown Los Angeles since 2003.
- The tank has a history of nitrification and is sampled three times each week for numerous nitrification-related water quality variables.
- A companion tank, Mount Washington Tank 1, provides a convenient control setting for side-by-side tests.

Four design features—reactor size and exposure intensity, duration, and waveband—distinguish the Mount Washington UV facility from all others. At more than 67,500 ft^3, Tank 2's UV reactor is the world's largest; daylong exposures to it of twilight intensities had never been attempted. The reactor pairs lowest exposure intensities with longest exposure times and is the first to use longwave UVA radiation instead of shortwave UVC radiation.

Constructed of reinforced concrete in 1954, Mount Washington Tank 2 has a diameter of 62.5 ft, maximum depth of 22 ft, and storage capacity of 524,000 gal. Theoretically, the transparency of water to UVA radiation can accommodate large dimensions and long detention times, which compensate for low-intensity exposures.

Test Results

Low-intensity UVA radiation can inhibit nitrifying bacteria in a tank as strongly as it does in nature.



LIGHTING DESIGN

Several laboratory and field studies have established that UVA radiation can inhibit the first step in nitrification, ammonia oxidation, at intensities < 0.1 percent of solar UVA during a 24-hr period. Solar inhibition of nitrifying bacteria has been implicated in the persistence of a prominent nitrite maximum at depths near the 1 percent light level throughout much of the world's oceans. Sunlight also suppresses ammonia oxidation in wastewater treatment plants. Sunlight contains considerable UVA, little UVB, and no UVC radiation.

Three optical criteria—the absorbance spectra of chlorophyll *a*, monochloramine, and water—were used to set wavelength boundaries for an ideal design spectrum. The monochloramine and chlorophyll absorbance spectra were used as bookends to minimize unwanted photolysis of disinfectant residual on the low end and unwanted algal photosynthesis on the high end. The water's absorbance spectrum was used to maximize the applied radiation's penetrating power.

To find the best UVA fit, the output spectra of several fluorescent and light-emitting diode (LED) lamps were measured with a scanning spectroradiometer. In terms of ready availability, spectral emission, spectral transmittance, and service life, an ordinary blacklight proved to be the best available technology.

A fluorescent blacklight waveband occupies a spectral optimum between shorter UVA wavelengths that penetrate water relatively poorly and longer violet-to-blue wavelengths that stimulate unwanted algal photosynthesis. The dominant photosynthetic pigment chlorophyll *a* strongly absorbs blue light. Although the violet-to-blue region of the solar spectrum inhibits nitrification at low intensities, it was excluded from the design spectrum to avoid possible growth of a green bathtub ring. In the future, UV LEDs may make it possible to target the spectral optimum more precisely.

Sizing the Mount Washington blacklight system posed a special design problem. For the first time, water transparency had to be factored into an overhead lighting plan. This was accomplished by using five years of underwater UVA attenuation measurements taken with a remote electro-optical sensor (REOS) in nearby Los Angeles Reservoir. The REOS system has been used by LADWP to track and treat nuisance algal blooms in Los Angeles Reservoir for nearly 20 years and was the enabling design technology for the Mount Washington UVA project.

Historical REOS data show that UVA transparency varies over time. However, when the Mount Washington tanks were full, water could be expected to transmit > 15 percent of UVA wavelengths 90 percent of the time. This 90th percentile transparency value was used with a commercial-lighting software tool to specify a surface intensity of 1 percent of solar UVA. This surface intensity was considered necessary to achieve a minimum design intensity of 0.1 percent of solar UVA in the tank's deepest, darkest

LADWP personnel are optimistic that low-intensity UVA radiation will prove to be a practical, safe, and effective safeguard against nitrification onset in water storage facilities.

reaches after accounting for radiant losses from surface reflection, distance from lamps, and absorbance by 22 ft of water.

LIGHTING VALIDATION

Measurements made by a pair of REOS radiometers suspended at different depths in Mount Washington Tank 2 revealed a complex UV field. As expected, when the tank's water level rose, underwater UVA intensity fell; and when the tank's water level fell, underwater UVA intensity rose. In addition, UVA radiation was about twice as intense near the tank's center as it was along the walls. UVA intensity on the bottom of a full tank near the wall exceeded minimum design specifications of 0.1 percent of solar UVA most of the time, with the surface intensity about nine times higher. Although difficult to quantify, horizontal, vertical, and temporal UVA gradients such as these provide a considerable design cushion because free-swimming bacteria in the water column are continuously exposed to UVA intensities higher than the design minimum.

As expected, absorbance of blacklight radiation by the water column had a spectral bias. The longer blacklight wavelengths penetrated about three times better than shorter ones. This bias is an important design consideration. With all other things being equal, the most penetrating wavelengths are the most efficient. For this reason, narrow-band LEDs are an attractive alternative.

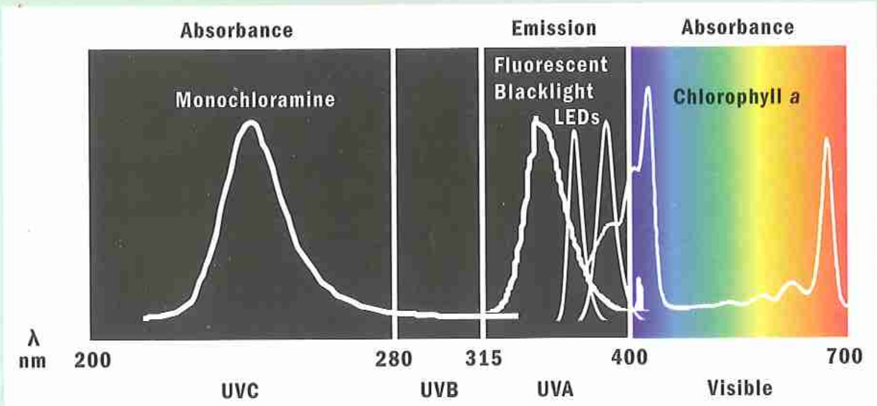
To test the pilot system's photoinhibitory effectiveness, three bottles containing water from the nearby Verdugo tank, which was just beginning to nitrify, were placed near the bottom of Mount Washington Tank 2, and another three bottles were placed in the unlit Mount Washington Tank 1 late one Friday afternoon. The test water had a starting nitrite concentration of 1.9 μM. When the Mount Washington test bottles were retrieved the following Monday morning, nitrite concentrations in the three bottles exposed to UVA radiation in Tank 2 were largely unchanged, but nitrite concentrations in the three bottles retrieved from the dark Tank 1 had more than quintupled. Meanwhile, during the same weekend, nitrite concentration in the Verdugo tank more than tripled.

Taken together, these observations support the underlying assumption that low-intensity UVA radiation can inhibit nitrifying bacteria in a tank as strongly as it does in nature. In addition, the routine nitrification-monitoring program showed that UVA radiation can accomplish this with no unforeseen consequences.

Nitrifying bacteria have attached and free-swimming life stages. Attached bacteria live year-round on bottom sediments and in biofilm that coats internal tank surfaces. Sediments and biofilm may shield attached bacteria from UVA radiation. Active nitrification, however, usually coincides with a bloom of free-swimming bacteria in the water column. Free-swimming bacteria would be fully exposed to and presumably inhibited by low-level UVA radiation. The relative contribution of attached and free-swimming bacteria to tank nitrification remains the largest unknown factor of the Mount Washington project.

Wavelength Boundaries

Fluorescent blacklight and UV LED wavebands occupy a spectral optimum between shorter UVA wavelengths and longer violet-to-blue wavelengths.



FUTURE WORK

As encouraging as the pilot results have been so far, much remains to be done. The lighting installation followed the simplest, round-the-clock, proof-of-concept design. Other configurations and photoperiods are conceivable; however, large-scale, long-term flow-through experiments in a series of tanks deep enough to absorb UVA radiation are needed to further assess and optimize the approach.

An experimental tank farm, known as the Subaquatic Inhibiting-Light Observatory, is nearing completion at the Los Angeles Aqueduct Filtration Plant. Four 17,000-gal covered tanks are already in the ground. Fabricated from 20-ft lengths of surplus 144-in. ASTM A36 rusted steel pipe, the tanks are plumbed to receive chlorinated or chloraminated water and are being equipped with dimmers, timers, mixers, and heaters. This facility allows different lamps and fixtures, radiation intensities, and photoperiods to be tested against an array of flow, temperature, and circulation conditions in the presence of natural biofilm. LADWP personnel are optimistic that low-intensity UVA radiation will prove to be a practical, safe, and effective safeguard against nitrification onset in water storage facilities.