UV AOPs for Taste and Odor Removal: Test to Design to Full-Scale Operation

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Abstract

Implementing UV AOPs for the control of taste and odor involves several steps that need to be followed carefully to assure proper design and cost-efficient operation.

Introduction

The taste and odor of drinking water is one of the most important indicators to assess if water is safe to drink. Ironically, most chemicals that can be harmful, even in low concentrations, do not influence either the taste or odor. On the other hand, 2-methylisoborneol (2-MIB) or geosmin, which are produced by cyanobacteria during an algae bloom, are not harmful in their natural occurring concentrations. Their impact on the taste and odor (T&O) of potable water, however, is so strong that utilities are faced with serious complaints or even exposure in the media when these compounds are present in concentrations of >5 ng/L. Therefore, utilities must implement treatment solutions that maintain consumers' trust in their drinking water supply.

Advanced oxidation processes (AOPs) have become widely accepted and commonly used treatment options to address issues related to harmful algae blooms (HABs). AOPs present a robust barrier against T&O compounds, as well as the toxins released by the cyanobacteria. This article provides guidance and examples for the implementation of UV-based AOPs for full-scale T&O applications.

Testing

As hydroxyl radicals (·OH) can react with almost all water constituents, the feasibility and efficiency of a UV-based AOP treatment should be tested prior to design. Modeling techniques have developed rapidly over the last decade leading to more precise predictions of the performance by incorporating the chemistry of the water to be tested. However, to eliminate uncertainties and the risk of over or under designing a system, a collimated beam test (CBT) is still the best way to develop the optimum design.

CB testing

To carry out a CB test, the utility needs to provide a sample of expected water quality during algae bloom season. Ideally the water should contain the target compounds (2-MIB or geosmin) in sufficient levels to allow demonstration of the required log reduction target. If the concentration of naturally occurring T&O compounds is too low, the best practice is to spike the sample with powdered 2-MIB. Note that the use of methanol dissolved 2-MIB standards is not recommended, since methanol is an ·OH radical scavenger influencing the results heavily. During the CB test, different UV and hydrogen peroxide doses should be trialed to develop dose response curves while also identifying the optimal balance between UV dose (energy costs) and hydrogen peroxide doses (chemical dosing and quenching costs).

As an alternative, the CB test procedure can be adjusted to determine the OH radical scavenging potential using the Methylene blue method or PCBA as a surrogate for ·OH radical specific reaction kinetics (Rosenfeldt et al., 2007). The advantage of this approach is that the handling of powered 2-MIB is not required, and the analytics may be less costly than 2-MIB specific analytics. The principal disadvantage, however, is that this method is indirect, and the customer does not get a specific demonstration of how the target contaminant is degraded, which may decrease trust and confidence in the proposed technology.

Figure 1 shows a typical CBT experiment set-up using a petri dish filled with sample water, which has been spiked with 2-MIB and hydrogen peroxide. Typical volumes necessary for one test set range between 100-500 mL.

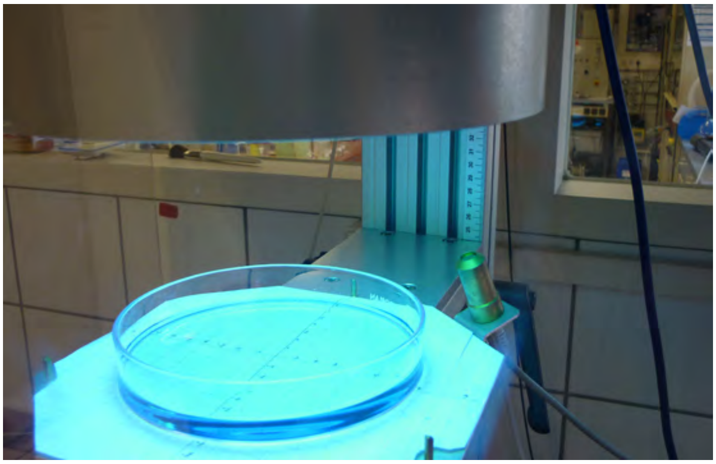

Figure 1. Typical CBT experiment set-up

Onsite testing

An alternative to CBTs is onsite pilot tests, which are especially recommended when the water quality fluctuates during the bloom season. An advantage of an onsite pilot is the demonstration of the technology in a 24/7 operation and the opportunity to educate operators and owners about the technology and to identify training needs for the reliable operation of a full-scale treatment system.

As the results arising from the pilot are the base of the design for the full-scale reactor it is necessary to deploy UV reactors that have known applied UV dose distributions under the conditions of the pilot. For this, two approaches have been found applicable:

1. Validation using a "chemical-assay"
The reactor must be operated in parallel to a CB device to develop UV dose response curves and to determine the reduction equivalent dose (RED) of the reactor. Once this is done, the exact applied UV dose is known and can be compared to existing modeling tools to extrapolate when parameters, such as flow rate or ultraviolet transmittance (UVT), are outside of the validated envelope.

2. Modeling using Computational Fluid Dynamic (CFD)
This approach uses computer based modeling tools to predict the applied UV dose considering UV intensity inside the reactor, as well as the hydraulic profile. It has been found that these REDs predicted by modeling tools are very close to the REDs measured in the field using approach number one (Scheideler et al., 2016).

The figures in the next column show how the chemical-assay must be set up to develop the design criteria for a full-scale UV AOP system by evaluating the Reduction Equivalent Dose (RED) of the pilot UV reactor.

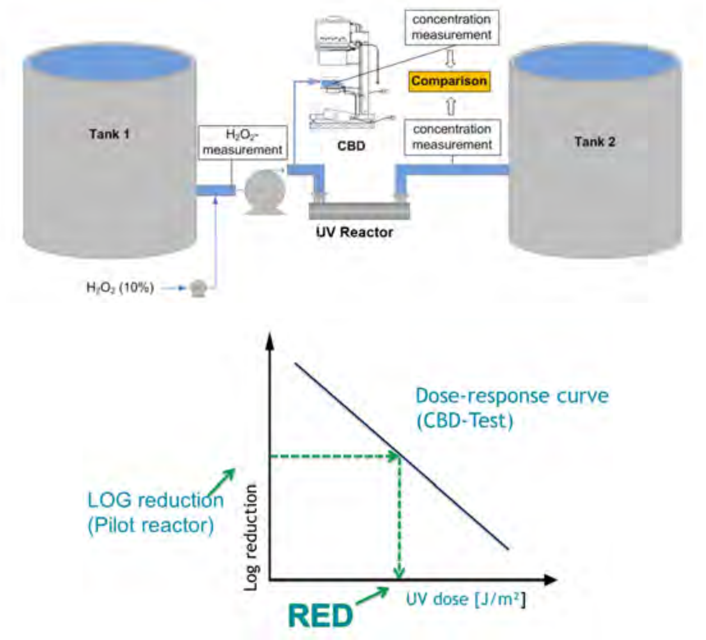

Figure 2. Onsite pilot reactor test with CBD in parallel to assess the RED

Design

Once the bench or pilot scale tests have been completed and dose response curves have been developed, the full-scale system can be designed considering the following important items:

- Flow rate and turn down requirements
- Duration of the T&O event
- Maximum log removal target
- Space available
- Local costs for electricity and hydrogen peroxide
- Potential quenching costs
- Water quality and fluctuations

UV-based AOPs are always a balance between the input of electrical energy (UV dose) and the costs for chemical dosing. As a rule of thumb, it can be assumed that doubling the hydrogen peroxide dose will result in a 50% lower UV dose, which will result in space, capital expenditure (CAPEX) and energy savings but significantly increases the costs for quenching and dosing. It is, therefore, recommended to perform a detailed life cycle cost analysis to identify the "sweet spot" between those two factors and at the same time ensuring that the system can react and be modified to changing conditions without the need for cost intensive upgrades. The graphs below show the outcome of such an analysis, comparing a design with a high hydrogen peroxide dose and a low hydrogen peroxide dose in correlation to how many days the system is operated in AOP mode. For the analysis a hypothetic water treatment plant with the costs and flows given in Table 1 was considered:

Table 1. Costs and flows

Parameter	Unit	Value
Flow rate	m^3/h	3,000
UVT	%	92
Energy costs	$/kWh	0.14
Hydrogen peroxide costs	$/kg	1.4
Sodium hypochlorite costs	$/kg	0.8
Depreciation time	Y	20

The quenching of residual hydrogen peroxide was simulated by dosing with a conventional sodium hypochlorite solution.

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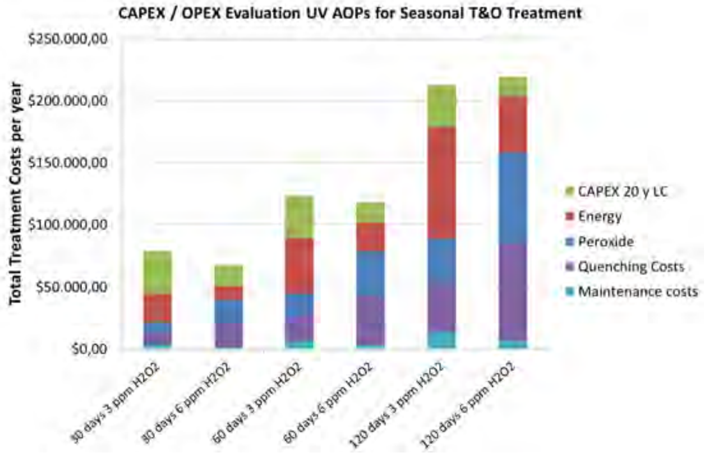

Figure 3. Impact of hydrogen peroxide dose and UV dose balance depending on the run time on operational expenditures (OPEX)

From this analysis, it can be concluded that for short run times, a smaller UV system with a higher hydrogen peroxide dosing is favorable, whereas for longer run times, the lower hydrogen peroxide dosing option is more economical.

Once the optimum level between UV and hydrogen peroxide doses is established, the full-scale UV reactor must be designed. In the past, up-scaling was done using the electrical energy per order (E_{EO}) approach, which simply considers the energy consumption of the pilot reactor for a one log removal of the target contaminant and extrapolates this to the total power requirement of the full-scale system. This approach works well when the pilot and the full-scale reactor are from the same manufacturer and the same product line using the same geometry and UV lamp technology.

Nowadays, however, more sophisticated approaches can be applied by using the UV dose determined by the CB tests, or onsite pilot tests to upscale to different styles of UV reactors and lamp technologies, or even to different manufacturers. This offers many advantages to the engineer or customer as the most suitable reactor geometry can be considered, benchmarking different vendors becomes easier, and the most efficient AOP system can be identified, resulting in potential CAPEX and OPEX savings. Table 2 shows the difference between a UV AOP system being up scaled by the E_{EO} and the UV dose approach. Using the EEO approach does not allow giving credit to a more energy efficient reactor, and, by this, potential costs savings are missed.

It is important that the engineer and manufacturers consider how best to upscale using the UV dose approach to ensure optimum design while avoiding an over designed UV AOP system with limited turn down capabilities. To address this either purely mathematical (Point Source Summation – PSS) or modeling (CFD) tools can be used to size the full-scale system. Both methodologies are well understood and have become industry standards for UV disinfection systems but are still relatively new for AOP applications. However, full-scale systems that have been designed using these methods have demonstrated their performance successfully in the field (Scheideler et al., 2016).

Another design aspect to be considered is the potential need for a hydrogen peroxide quenching step. Since only 10% of the added hydrogen peroxide is consumed in the AOP, there is often the need to quench the residual to avoid interference of the hydrogen peroxide with downstream treatment processes. Two methods have been found to be applicable using chlorine dosing or activated carbon for quenching. Whereas the quenching with chlorine purely removes the residual hydrogen peroxide, the downstream filtration using granular activated carbon that often becomes biological active offers several benefits for the overall treatment. Besides, effective quenching oxidation by products that have been formed during the AOP are effectively adsorbed and metabolized by the microorganisms leading to a true removal of the organic micropollutants (Wang et al., 2016).

Operation

Once installation and commissioning are complete it is time to plan the full-scale performance tests to confirm the design and operational set-points while also collecting data for potential optimization of the full-scale system to improve overall life cycle costs. If 2-MIB or Geosmin are not naturally present, it is possible to dose powdered 2-MIB. However, this is a very cost-intensive option, especially for large flow rates,

Table 2. E_{EO} vs. the UV dose approach

	E_{EO} Approach		**UV Dose Approach**	
	Reactor A	**Reactor B**	**Reactor A**	**Reactor B**
UV Dose (mJ/cm²)	600	750	600	600
Electrical Energy Demand (kWh/m³)	75	75	75	50

and may be associated with environmental safety, security and health (ESH) concerns as a chemical is being added to the actual drinking water treatment process. A more cost-effective solution is the use of a surrogate compound that is less harmful and does not influence the quality of the drinking water. Caffeine has been described as a superior surrogate due to its similar kinetic rate constants compared to 2-MIB and its easy availability (Wang et al., 2015).

If possible, a CB test should be conducted in parallel to the performance test to assess if the specified UV dose is delivered by the full-scale system. This will assure the customer that the system meets all specified requirements and up-scaling has been completed properly by the manufacturer.

Following the performance tests, the customer will understand how to set the system to ensure 100% compliance and first optimization potentials should have been identified. The biggest challenge, however, is to develop control strategies that allow for operational cost savings by applying only the UV and hydrogen peroxide doses necessary to reduce T&O below the notification level.

As online monitors to directly measure the scavenging potential are not currently available, surrogate measurements must be taken and the results fed back to the UV AOP system. Then either the chemical feed and power input can be reduced, or increased, as necessary. The following parameters typically affect the scavenging potential most frequently:

- TOC/DOC
- Alkalinity
- pH

For all these parameters, online instruments are available and their signal can be used to adjust the AOP system in real time. This does not mean that the scavenging potential can be exactly predicted as the TOC/DOC value does not consider the type of organic, but it will be relatively accurate as most of the natural organic matter in reservoirs and rivers does not totally change its composition. Considering this, the control of the UV AOP system still should contain some conservatism, bearing in mind that the true scavenging potential cannot be reflected by the above-mentioned surrogate measurements.

By incorporating online instruments, the selection of the right UV and hydrogen peroxide doses can be fully automated assuring proper level of treatment through the entire T&O period.

Conclusions

UV AOPs have demonstrated their feasibility and reliability as an easy to operate treatment barrier against algae bloom related T&O issues. The challenge is the proper design of the system to avoid unnecessarily high operational costs or insufficient treatment. Following the guidelines and the recommended steps outlined here will ensure the selection of the most appropriate and efficient design based on the established UV and hydrogen peroxide dose for the specific project site. ■

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