Treating Algal Toxins Using Oxidation, Adsorption, and Membrane Technologies [Project #2839]

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OBJECTIVES:
The study's primary objective was to identify and assess viable control and treatment methods, including design and operating criteria and estimated treatment costs, to mitigate algal toxins in finished water. The following microcystin removal technologies were investigated:

- Ultraviolet/hydrogen peroxide (UV/H_2O_2)
- Ozone and oxidation
- Powdered activated carbon (PAC)
- Granular activated carbon (GAC)
- Nanofiltration (NF) and reverse osmosis (RO) membranes

BACKGROUND:
Groundwater availability is quickly diminishing in fast-growing Florida, where the demand for potable water is burgeoning. Consequently, water utilities increasingly are turning to surface water sources to supply the demand for drinking-quality water. As they do, they encounter potential public health risks associated with algae and cyanobacteria and related toxins such as microcystin.

Cyanobacteria and other toxin-producing algae have been observed to adversely affect animal, environmental, and human health. They can also reduce the aesthetic quality of source waters and clog water filtration systems. Toxins can enter the domestic water supply through natural production and metabolic activities and through cell lysis, in which damaged algal cells release toxins, possibly during water collection and treatment.

Algal toxins' harmful effects on animals have been observed for more than 200 years. Their presence in surface waters has become a significant issue in recent years, resulting in guidance and regulation into the foreseeable future. The research in this regard has indicated that algal toxins can be removed by oxidation, activated carbon adsorption, and membranes.

APPROACH:
This project consisted of three simultaneous investigations:

- Identification and measurement of algal toxins in three Florida surface waters
- Determination of oxidation, adsorption, and membrane design characteristics
- Development of implementation and cost considerations for treatment technologies

Background was developed on algal toxins, including identification of toxins commonly found in surface water sources and a risk assessment for their potential impacts to human health. A raw-water characterization was completed for three Florida surface waters to quantify the presence of algal toxins in relation to seasonal changes. Bench-scale studies were conducted to evaluate the effectiveness of each treatment process and to develop design criteria for microcystin-LR (m-LR) removal.

Scientific and engineering data were developed to characterize treatment approaches. These included development of reaction rate constants for ozone and advanced oxidation; isotherms, adsorption rates, and wave front size and shape for PAC and/or GAC; and exclusion and rejection characteristics of NF and

RO membranes. Engineering application and cost information also was developed for each treatment technology.

The effectiveness of each process was measured by challenging it with source waters (feed water) spiked with m-LR during testing. Common characteristics of the bench-scale experiments include the source waters tested, and the methods and procedures for preparing and measuring m-LR. The source waters used for the bench-scale studies were surface waters in Florida (Lake Washington) and Oregon (Willamette River). Evaluations were conducted by spiking one or both with varying m-LR concentrations.

Cost estimates for each treatment process were developed using CH2M HILL's cost-estimating standard procedures. The estimates are considered order-of-magnitude cost opinions, prepared without detailed engineering or consideration of site-specific conditions. Estimates of this type are normally considered accurate to within -30 to +50 percent.

RESULTS/CONCLUSIONS:

- Based on the collimated-beam tests, UV/H_2O^2 (advanced oxidation process, UV/AOP) can effectively treat m-LR. By itself, UV photolysis is not effective for m-LR destruction. The effectiveness of the process depends on the UV dose and the hydrogen peroxide dose as adjusted for a specific raw water quality.
- The results of this research indicate that ozone doses and contact times typically used for disinfection can be adequate for microcystin removal under most water quality conditions encountered in the treatment of drinking water.
- PAC performed well overall, with removal efficiencies greater than 60 percent at PAC doses of 10 mg/L, contact times of 30 minutes, and initial m-LR concentrations at or below 1,100 nanograms per liter (ng/L).
- GAC adsorption was very successful at removing microcystin. However, the GAC may need to be replaced at a more frequent rate than most utilities are currently using in processes such as filter adsorbers.
- Biological degradation provided only 35 percent removal of m-LR in this study.
- All of the tested membranes removed at least 95 percent of the algal toxin under the most challenging conditions (highest flux and highest recovery).

APPLICATIONS/RECOMMENDATIONS:

This project developed chemical and engineering criteria necessary to understand the impact of changing water quality and conditions on m-LR treatment efficiency. This project also developed recommendations regarding facility design requirements and operational impacts for m-LR treatment.

The primary treatment, design, and operational recommendations to utilities for m-LR treatment are summarized as follows:

- Based on the collimated-beam tests, UV/H_2O_2 (advanced oxidation process, UV/AOP) can effectively treat m-LR. By itself, UV photolysis is not effective for m-LR destruction. The effectiveness of the process depends on the UV dose and the hydrogen peroxide dose as adjusted for a specific raw water quality.
- For ozone treatment, only pH and ozone dose had significant effects in oxidation scenarios similar to those present in a water treatment plant. Ozone was more effective at pH values less than 7. Doses as low as 0.4 mg/L achieved m-LR removals greater than 97 percent under acidic conditions (less than pH 6). Higher ozone doses may not be necessary under low pH conditions. The results of this research indicate that ozone doses and contact times typically used for disinfection can be adequate for microcystin removal under most water quality conditions encountered in the treatment of drinking water.
- PAC provided reasonably effective treatment of m-LR, given sufficient reaction time, and the data suggest that adsorption of m-LR onto PAC is relatively rapid (roughly 50 percent removal within 5

minutes). Therefore, long contact times may not be needed for many treatment scenarios. PAC doses greater than 10 mg/L did not significantly improve treatment effectiveness for the conditions tested in this study.

- GAC adsorption was very successful at removing microcystin. However, the GAC may need to be replaced at a more frequent rate than most utilities are currently using in processes such as filter adsorbers. TOC breakthrough occurred more rapidly than m-LR. At an EBCT of 5 minutes, m-LR removal was affected by the feed-water TOC concentration. At EBCTs of 10 and 15 minutes, removal was not significantly affected between 20,000 and 25,000 bed volumes of treated water.
- The results of this study indicate that m-LR is reduced by biological degradation approximately 30 percent at an EBCT of 2 minutes, but no significant increase in removal occurred at higher EBCTs. The testing also showed minimal degradation of DOC. Biological degradation provided only 35 percent removal of m-LR in this study. Thus, it should be used as a polishing step in conjunction with other treatment methods such as UV oxidation, ozonation, PAC, and GAC.
- The membranes tested in this study removed the m-LR algal toxin efficiently, regardless of flux and recovery. At the most challenging conditions (lowest flux and highest recovery), toxin passage was less than 5 percent. Higher flux generally resulted in higher toxin passage. All of the tested membranes removed at least 95 percent of the algal toxin under any condition. Membranes can be used for reasons other than algal toxin oxidation, such as taste and odor control and removal of organics and inorganics, and one of these objectives often will determine the size of the membrane system.

The above summarizes industry-relevant data that are applicable to algal toxin treatment. This work has provided the basis for other utilities' assessment of treatment and will assist significantly in contributing to their own investigations and decisions.

RESEARCH PARTNERS:

- City of Cocoa, Florida
- St Johns River Water Management District
- City of Melbourne, Florida