Planktonic

In-water Intervention and Prevention Strategy
Limited Supporting Field Data

Benthic

In-water Intervention and Prevention Strategy
No Available Supporting Field Data

Ozonation is an advanced oxidation technique that works by infusing ozone gas into water. There is a long history of process-level ozonation use to disinfect drinking water and wastewater (Loeb et al. 2012, Rice 1991). Ozone attacks the chemical bonds within cyanotoxins and other compounds, leading to rapid degradation. Ozone treatment requires on-site generation of ozone gas, due to a short half-life of the compound. In general, ozone is produced by passing purified air through an electric discharge to convert oxygen to ozone. Ozone is not readily soluble in water, particularly compared to other oxidative compounds such as chlorine, so it requires a delivery mechanism such as a diffuser for application. Application methods vary but do require on-site infrastructure for application. Ozonation has substantial documentation for applications in both drinking water and wastewater processing and ozone nanobubbles have been used in ponds, lakes, and bays to reduce planktonic chlorophyll concentrations (for example, NBS 2018). It is also a fourth step in the surfactant-flotation-skimming-ozonation technique described in the skimming and harvesting strategy.

Except for nonreplicated ozone nanobubble projects in Asia and Florida, ozonation is still a research technique for the treatment of HCBs in surface waters, with no current peer-reviewed literature on surface water treatment. Ozonation has been shown to oxidize multiple cyanotoxin classes (Newcombe and Nicholson 2004). For example, pilot and laboratory work suggest that significant reductions in microcystin concentrations can be achieved with an ozone concentration of at least 0.3 mg/L and a contact time of at least 5 minutes. Similar results were also observed for anatoxin-a at somewhat higher ozone concentrations (Newcombe and Nicholson 2004). The amount of dissolved organic carbon in the water strongly affects the efficacy of ozone treatment on cyanotoxins (Staehelin and Hoigne 1985). Ozonation also shows promise in lysing HCB organisms directly and has been shown experimentally to lyse cells of several genera, including *Microcystis* spp., *Dolichospermum* spp., *Aphanizomenon* spp., and *Pseudanabaena* spp. (Pandhal et al. 2018, Zamyadi et al. 2015).

PLANKTONIC AND BENTHIC
EFFECTIVENESS • Water body type: Pond, lake/reservoir, river • Any surface area or depth • Any trophic state • Any mixing regime • Water body uses: Drinking water, treated wastewater/effluent
NATURE OF HCB • Shown as useful in drinking water treatment for reservoirs and other source waters with chronic blooms • Can kill *Microcystis* and other cells with sufficient contact time • Intervention strategy
ADVANTAGES • Ozone treatment in benchtop applications has been shown to be capable of completely oxidizing multiple cyanotoxin classes, including microcystins, anatoxin-a, and cylindrospermopsin. However, it has not been shown to oxidize saxitoxins efficiently (Cheng et al. 2009, Fawell et al. 1993, Newcombe and Nicholson 2004, Onstad et al. 2007, Rositano et al. 2001). • Ozonation can also lyse cells, with the effectiveness depending on the ozone concentration and contact time; with cyanotoxin oxidation noted above, ozonation is a possible broadly applicable technique. • Ozone also removes many other water impurities, including taste and odor compounds (Ho, Newcombe, and Croué 2002), *Cryptosporidium*, and multiple organic compounds.

LIMITATIONS

- Ozone treatment is likely not suitable for a one-time application, as it must be generated on-site.
- Ozone treatment has an extremely high oxidation potential and is nonselective in the organisms that are killed (both HCB and non-HCB organisms).
- Ozone treatment generally results in cell lysis, which could release cyanotoxins contained within HCB cells.
- The effectiveness of ozone treatment is impacted by the concentration of organic matter in the system; therefore, it may require pretreatment if organic matter loads are high.
- Ozone treatment does not leave residuals; therefore, treatment is short-lived and requires reapplication.
- If the water’s metal content is high, ozonation will form insoluble metal oxides that would potentially need to be removed.
- Applicator protection may be required.

Treatment of HCB events in surface water via ozonation is still in development. This technique has been applied in several field situations via dispersal of ozone nanobubbles to reduce planktonic chlorophyll concentrations (NBS 2018),without any species information however. Currently, there is no available information on the effectiveness of ozone in treating benthic cyanobacteria mats. It is likely that the known limitations of the technique would limit its applicability on benthic populations. Ozonation remains an emerging strategy, as it is still largely a research technique.

COST ANALYSIS

Large-scale ozonation use is estimated to be the most expensive of the advanced oxidation processes, according to a cost analysis conducted by Dore et al. (2013) for smaller systems. Primary expenses are capital costs, which can be in the millions, and yearly operational costs, which can be in the hundreds of millions. Dore et al. (2013) estimated that ozone treatment could cost between \$0.10 and \$0.50/m^3 water, with costs decreasing precipitously at treatment volumes >10,000 m^3/d.

Relative cost per growing season: Ozonation

ITEM	RELATIVE COST PER GROWING SEASON
Material	\$\$\$
Personal Protective Equipment	\$\$
Equipment	\$\$\$
Machinery	\$\$\$
Tools	\$\$\$
Labor	\$\$\$
O&M Costs	\$\$\$
Delivery	\$\$\$
OVERALL	**\$\$\$**

REGULATORY AND POLICY CONSIDERATIONS

Use of ozonation at the process level requires an investment in infrastructure, but the technique is already used in many cities throughout the United States in drinking water and wastewater treatment plants. Use of ozonation has been accepted in these applications for many decades (Loeb et al. 2012). Ozonation for treatment of active HCB events in surface waters might be feasible in the future (for example, via nanobubbles), but at present it remains a research technique. Excess ozone will naturally convert to oxygen, although at very high concentrations ozone can damage fish gills. With ozone monitoring, ecosystem impacts of treated water can be minimized, likely increasing public acceptance of the method compared to chemical applications and their residuals. Human exposure to high ozone levels should be avoided and permits for its use should be explored.

CASE STUDY EXAMPLE

Laboratory-scale: Pandhal et al. (2018) conducted a benchtop study using a novel ozone generation and application method. The study used a low-temperature plasma dielectric barrier discharge reactor and a fluidic oscillator diffuser, which has lower energy requirements than other systems. Together, this method delivers ozone in microbubbles, which increases the solubility of ozone and therefore increases the contact time.

This study showed that microbubble delivery of ozone via this system rapidly degrades microcystins, with complete oxidation of MC-LR in 2 minutes at an ozone flow rate of 1 L/min. Importantly, the treatment showed a large decrease in toxicity of the microcystin, with the microcystin by-products showing a substantial decrease in inhibitory activity. Lysis of *Microcystis aeruginosa* cells was observed within 20 minutes.

Alternative ozone generation and delivery technologies such as described in Pandhal et al. (2018) have the potential to lower the operation costs of ozonation, making the treatment more affordable in the future.

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