Ozone: Changing the Landscape of Waterborne Outbreaks

By Kelly A. Reynolds, MSPH, PhD

Ozone disinfection applications have been instrumental in preventing waterborne outbreaks due to drinking and recreational water exposures. Although not a new technology, the benefits of such advanced oxidation practices to destroy microbial pathogens and other contaminants are being increasingly realized. Given the changing practices of waste management and water reuse, and the continued emergence of pathogens resistant to conventional chlorine disinfectants, ozone is gaining renewed popularity in food and water treatment industries.

History of ozone use in water treatment

Ozone is a highly reactive molecule composed of three oxygen atoms. In the upper atmosphere, ozone forms a layer of protection against the sun's harmful UV light but in the respirable region, the gas can be a lung irritant, triggering asthma attacks and other adverse health effects. When produced under controlled conditions, however, the oxidizing power of ozone can be harnessed and utilized to destroy harmful microbes contaminating food, water and even surfaces.

Ozone was first used to treat drinking water in 1893 in the Netherlands and by 1920 it was widely used across Europe.[1] Although known to be highly effective at destroying viruses and bacteria, ozone was overshadowed by chlorine and, thus, its popularity did not spread globally. Chlorine was cheaper and had the benefit of a residual effect, thus emerging as the primary water disinfectant by the 1970s. For the next two decades, chlorine would remain the primary disinfectant for treated drinking water sources and swimming pools. Moving into the 90s, however, recognition of additional, difficult to treat contaminants grew. Conventional chlorine disinfectants could not eliminate the wide range of pesticides and pharmaceutical products detected in water. Evidence of chlorine-related DBPs (i.e., trihalomethanes) and their association with cancer, and the emergence of chlorine-resistant pathogenic protozoa, caused a renewed interest in alternative disinfectants such as ozone.[1]

Today ozone is used to mitigate a wide range of water treatment concerns. In addition to controlling microbial pathogens, ozone oxidizes inorganic compounds (including metals such as iron and manganese), which effectively improves water aesthetics including color, odor and taste. Further benefits are the oxidation of synthetic organic compounds (including pesticides) and removal of natural organic compounds, such as trihalomethane precursors. Ozone also reduces TOC concentrations and algal toxins.

Chlorine-resistant pathogens

Numerous studies have shown ozone to be two to three orders of magnitude more efficient than chlorine disinfection against microbial pathogens.[2] In a comparison with chlorine dioxide, free chlorine and chloramines, ozone ranked best for biocidal efficiency but worst for stability. Due to its instability, ozone cannot be stored in pressurized vessels and transported like chlorine. Instead, it must be generated onsite, which could be a burden for large-scale water treatment plant operations. Another benefit of ozone is that pH variation (range 6-9), which has a detrimental effect on free chlorine efficiency, has little effect on ozone.[1]

Protozoan pathogens, like *Cryptosporidium, Giardia* and some human viruses such as norovirus are resistant to chlorine. Even at concentrations as high as 10 ppm free chlorine, a contact time of over 25 hours may be required to reduce 99.9 pecent of *Cryptosporidium* compared to only minutes with relatively low concentrations of ozone. Ozone oxidizes the cell walls of microbes, destroying their integrity and allowing internal contents to leak out. Further, ozone free radicals damage cellular nucleic acids, leaving little chance for recovery. Commonly, ozone is used in combination with low levels of chlorine residual for additional protection through distribution. Ozone will also produce disinfection products (in particular bromates), which are a possible human carcinogen. US EPA's maximum contaminant level (MCL) for bromate is 10 ppb. Bromate production can be controlled in ozonated waters by sourcing waters below 100 µg/L bromide concentrations, lowering water pH (to 6.5-7) or using small amounts of chemical additives prior to treatment.[3]

Impact on waterborne outbreaks

Cryptosporidium was first diagnosed in humans in 1976 and the first documented US outbreak was in 1985. The associated illness became a nationally notifiable disease in 1994 after Milwaukee, WI experienced the largest reported waterborne outbreak in US history. The outbreak occurred in 1993 with over 403,000 people infected (approximately half of the population served by the affected treatment plant), 69 attributable deaths and an estimated economic burden of $96 million dollars due to healthcare costs and productivity losses.[4] During the time of the outbreak, water quality monitoring data from the associated water treatment plant indicated an increase in turbidity in the Lake Michigan source waters but levels were in compliance with federal standards.

Humans and cattle are common reservoirs for *Cryptosporidium* infection and excretion of the oocyst contributes to high concentrations in surface waters. One survey found that up to 100 percent of surface waters tested positive but even groundwater supplies are vulnerable, with up to a 22-percent prevalence rate.[5] Environmental and anthropogenic factors such as rainfall, sewage treatment and animal waste management are key contributors to waterborne risks.

Part of the problem in Milwaukee was that their conventional treatment works, including chlorination, alum coagulation, mechanical flocculation, sedimentation and rapid sand filtration were not able to achieve necessary log reductions during high contaminant loads. Milwaukee Water Works' five-year, post-outbreak response strategy included renovation of the treatment works to improve source-water protection and filtration practices, while adding dual disinfection trains involving both ozone and chlorine.

Needs for outbreak control

Utility incorporation of ozone has been driven in part by federal regulation, including: the *Interim Enhanced Surface Water Treatment Rule*, the *Long-Term 2 Enhanced Surface Water Treatment Rule* and the *Stage 2 Disinfectants and Disinfection By-Products Rule*. Increased water reuse activities and awareness of unregulated contaminant exposures of uncertain effect necessitates the use of advanced treatment and disinfection options. For example, for safe reuse and improvement of raw wastewater to drinking water quality may require a 12-log removal of viruses.[6]

Ozone's popularity extends from municipal water utilities and public pools to backyard pools and household taps. The technology has the potential to greatly impact food and waterborne outbreaks globally. Ozone has been found to effectively extend the safety, quality and shelf life of a variety of foods, including meats, vegetables, fruit, fish, spices and beverages.[7] Benefits to the food industry include the absence of a chemical residue, reduction of pathogenic and spoilage microbes. High ozone doses, however, may result in loss of nutrients, aroma, texture and taste, depending on the food product.

Further, *Cryptosporidium* outbreaks in public swimming pools remain poorly managed, given that chlorine is the primary pool disinfectant and largely ineffective against the protozoa. In 2014, the CDC published the *Model Aquatic Health Code (MAHC)* recommending the use of ozone as a secondary pool disinfectant with quality targets of at least a 3-log, or 99.9 percent reduction of *Cryptosporidium* and a maximum residual concentration of 0.1 ppm in swimming pool water.[8] Although it is difficult to quantitatively prove that the increased use of ozone technologies resulted in a marked reduction of waterborne outbreaks, the technology has shown consistent benefits for improved water quality and promises to trend toward increased use in multiple applications.

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