Ozone

Summary

New water treatment goals for disinfection byproducts (DBP) and for microbial inactivation will increase the need to consider new disinfection technologies. Ozone is an attractive alternative. This technology has evolved and improved in recent years, thereby increasing its potential for successful application. It is important to note that ozone, like other technologies, has its own set of advantages and disadvantages that show up in differing degrees from one location to the next.

What is ozone?

Ozone is a colorless gas that has an odor most often described as the smell of air after a spring electrical thunderstorm. Some people also refer to the odor as similar to the smell of watermelons. Ozone (O_3) is an extremely unstable gas. Consequently, it must be manufactured and used onsite. It is the strongest oxidant of the common oxidizing agents. Ozone is manufactured by passing air or oxygen through two electrodes with high, alternating potential difference.

What regulations govern ozone?

In the next century, small water systems will need to use disinfection methods that are effective for killing pathogens without forming excessive DBP. Disinfection byproduct compliance is more likely to be a problem for small water systems treating surface water than for those treating groundwater because surface water sources tend to contain more natural organic matter that forms byproducts when mixed with disinfectants.
In August 1997, the U.S. Environmental Protection Agency (EPA) listed ozone as a "compliance" in the requirements of the Surface Water Treatment Rule for all three sizes of small drinking water systems.

Advantages

Using ozone to treat water has many advantages, including the following:

- Possesses strong oxidizing power and requires short reaction time, which enables the germs, including viruses, to be killed within a few seconds;
- Produces no taste or odor;
- Provides oxygen to the water after disinfecting;
- Requires no chemicals;
- Oxidizes iron and manganese;
- Destroys and removes algae;
- Reacts with and removes all organic matter;
- Decays rapidly in water, avoiding any undesir able residual effects;
- Removes color, taste, and odor; and
- Aids coagulation.

Limitations

The use of ozone to treat water has some limitations:

- Toxic (toxicity is proportional to concentration and exposure time);
- Cost of ozonation is high compared with chlorination;
- Installation can be complicated;
- Ozone-destroying device is needed at the exhaust of the ozone-reactor to prevent toxicity and fire hazards;
- May produce undesirable aldehydes and ketones by reacting with certain organics;
- No residual effect is present in the distribution system, thus postchlorination is required;
- Much less soluble in water than chlorine; thus special mixing devices are necessary; and
- It will not oxidize some refractory organics or will oxidize too slowly to be of practical significance.

Disinfection

Design of an ozone system as primary treatment should be based on simple criteria, including ozone contact concentrations, competing ozone demands, and a minimum contact time (CT) to meet the required cyst and viral inactivation requirements, in combination with EPA recommendations.

Systems that need to provide CT to comply with the Ground Water Disinfection Rule, but are also having problems with DBP or maintaining distribution system residuals, should consider using ozone as the primary disinfectant and then chloramines for distribution system protection.

Ozone has been observed to be capable of disinfecting *Cryptosporidium*, and there is significant interest in this aspect of its application. Available data indicate that a significant increase in ozone dose and CT may be required as compared with past practices. Therefore, these needs should be considered in planning.

Iron and Manganese Removal
The standard oxidation-reduction potential and reaction rate of ozone is such that it can readily oxidize iron and manganese in groundwater and in water with low organic content. Groundwater systems that have iron levels above 0.1 milligrams per liter (mg/L) may have iron complaints if ozonation or chlorination is added.

Excessive doses of ozone will lead to the formation of permanganate, which gives water a pinkish color. This soluble form of manganese (Mn) corresponds to a theoretical stoichiometry of 2.20 mg O_3/mg Mn. Stoichiometry is the determination of the proportions in which chemical elements combine or are produced and the weight relation in a chemical reaction.

Color Abatement
Because humic substances are the primary cause of color in natural waters, it is useful to review the reactions of ozone with humic and fulvic acids. According to different authors, ozone doses of 1 to 3 mg O_3/mg C lead to almost complete color removal. The ozone dosages to be applied in order to reach treatment goals for color can be very high. It is interesting to note that when the ozone dosage is sufficient, the organic structure is modified such that the final chlorine demand can decrease.

Control of Taste and Odor
The National Secondary Drinking Water Regulations recommend that the threshold odors number (TON) be 3 or less in finished water. It has been shown that ozone can be effective in treating water for taste and odor problems, especially when the water is relatively free from radical scavengers.

It has also been observed that ozone, in combination with other downstream treatment processes, especially granular activated carbon (GAC) filtration, can greatly increase taste and odor treatment efficiency and reliability. Again, the cause of taste and odor compounds, as well as the source water to be treated, need to be carefully considered prior to designing a treatment system. Analysis and possibly pilot-scale experimentation may be required to determine the optimum choice of ozone and downstream treatment.

Elimination of Synthetic Organic Chemicals
Ozone or advanced ozonation processes can remove many synthetic organic chemicals (SOC). This removal leads to the chemical transformation of these molecules into toxic or nontoxic byproducts. Such transformation can theoretically lead to complete oxidation into carbon dioxide (CO_2); however, this is rarely the case in water treatment. Any observable reduction in total organic carbon (TOC) is due either to a small degree of CO_2 formation (for example, decarboxylation of amino acids) or the formation and loss of volatile compounds through stripping.

Effects on Coagulation
It is important to understand that the coagulating effects of ozone go beyond any direct oxidative effects on organic macro-pollutants. For this reason, one must be wary of studies claiming improved removal of organic matter when the data are based solely on color removal or ultraviolet (UV) absorbtion. Also, when studying the removal of DBP (for example, trihalomethanes), one must be careful to incorporate controls permitting the separate evaluation of ozone's direct effects. Finally, the coagulating effects of ozone may not be observed with all water. Whenever considering the use of ozone as a coagulant aid, the pre-ozonation effects should be critically evaluated in pilot studies incorporating the proper controls.

Algae Removal
Ozone, like any other oxidant, such as chlorine or chlorine dioxide, has a lethal effect on some algae or limits its growth. Ozone is also capable of inactivating certain zooplankton, e.g., mobile organisms, *Notholca caudata.* Such organisms must first be inactivated before they are removed by flocculation and filtration.

Byproducts
The alternative use of ozonation has generated much interest because of its ability to avoid the formation of halogenated organics inherent in the practice of chlorine treatment. However, raw water quality significantly affects ozonation results and could lead to the formation of other undesirable byproducts. Brominated byproducts are a major concern in source waters containing bromide. Ozonation produces its own byproducts, such as aldehydes, ketones, and carboxylic acids. Assuming equivalent disinfection, benefit is achieved as long as the health concerns for the new products are less than those for the chlorine byproducts.

Personnel Requirements
Personnel time requirements for system cleaning may be fairly substantial. However, recent advancements in ozonation technology include use of high purity oxygen feed systems, rather than ambient air-feed systems. Ozonation treatment is therefore said to run cleaner and require less cleaning-related maintenance than had the earlier versions of this technology.

No Residual
Ozone will not provide a disinfecting residual that protects finished water in the distribution system. Therefore, the role of chlorine as a disinfecting agent is not entirely replaced, and its use in either the free chlorine or chloramine form will be required for this purpose in many locations.

Process and Equipment
The basic elements of an ozone system include ozone generation, feed gas preparation, ozone contacting, and ozone off-gas destruction components. While many of these components can involve a high degree of sophistication in large facilities, less complex alternatives are available for smaller systems. Figure 1 (see below) shows the five basic components of an ozonation system. To insure effectiveness and safety simultaneously, all components must be taken into account when designing/ installing an ozone system. Central to the ozonation system is the ozone generator itself, which in turn is connected to an appropriate power supply. Instrumentation and controls for ensuring the effective and safe operation of the total system may be added to the five-component system shown in Figure 1.

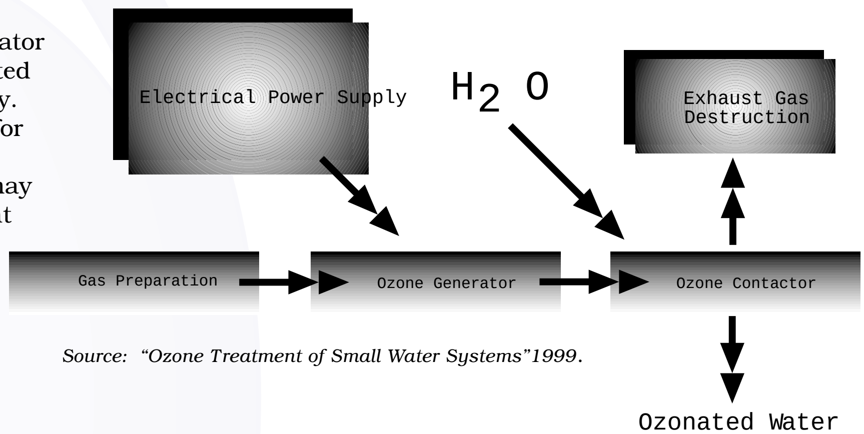
Feed Gas Preparation
The feed gas preparation component is critical, as a high-quality gas stream is required for the generator to perform properly. This requires a gas stream that is low in moisture and particles. In older air-feed systems, the feed gas preparation systems for small systems tended to rely on high-pressure compressors that produce a pressurized feed stream, which is easier to dry and can accom- modate simpler, less maintenance-intensive drying devices than were typically applied in larger systems where lower-pressure compressors are typically used.

Alternatives for application of oxygen-rich feed gas streams have also emerged for small system applications in recent years. These include purchasing liquid oxygen and using small package oxygen-generation systems that are based on pressure swing adsorption. The use of these oxygen-enriched feed streams allows improved electrical efficiency in ozone generation and yields a product stream with a higher ozone content.

Ozone Contactors
Since ozone is only partially soluble in water, once it has been generated it must contact water to be treated. Many types of ozone contactors have been developed for this purpose.

Ozone contacting for disinfection has typically been accomplished in deep, multistage contactors that employ fine bubble diffusers. Newer alternatives have emerged that provide an option for small systems through the use of side-stream injection technologies that eliminate the need for fine bubble injection. Package units are available that include a gas separator that fuses and eliminates excess gas that results from ozone addition and a venturi jet that is used to inject and blend the ozone with a solution feed stream. These systems allow the alternative of injecting ozone into an enclosed vessel or a pipe. Note that materials need to be compatible with ozone. One possibility in this regard is the use of stainless steel. Several other contacting configurations, including turbine mixers, have been developed and may provide benefits as well.

Figure 1. Basic Components of an Ozonation System



Source: "Ozone Treatment of Small Water Systems" 1999.

Exhaust Gas Destruction
Ozone off-gas destruction is the final major component in the ozonation process. This system is required to remove ozone from spent off-gas streams, which are collected and treated prior to discharge into the atmosphere. Both catalytic and thermal destruction devices are used for this purpose or by passage through GAC.

How safe is ozone?
EPA notes that ozonation technology requires careful monitoring for ozone leaks, which pose a hazard in the work place. As with any other chemical, the Occupational Health and Safety Administration (OSHA) has established maximum contaminant inhalation guidelines for ozone in the work place. Ozone concentration of 0.1 part per million inhaled during an eight hour work period in a work area is the maximum limit set by OSHA regulations.

Where can I find more information?

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(3) Collins, M.R. 1998. *Small Systems Water Treatment Technologies: State-of-the-Art Workshop.* Denver: American Water Works Association.

(4) International Ozone Association. 1999. Regional Conference on Ozonation and Advanced Oxidation Processes (AOPs) in Water Treatment. *Applications and Research in Poitiers, France. Stamford: International Ozone Association.*

(5) Langlais, B., D.A. Reckhow, and D.R. Brink. 1991. *Ozone in Water Treatment: Application and Engineering*. Denver: AWWA Research Foundation and Lewis Publishers.

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(7) Vigneswaran, S. and C.Visvanathan. 1995. *Water Treatment Processes: Simple Options*. Boca Raton: CRC Press, Inc.

(8) U.S. Environmental Protection Agency. 1998. *Small System Treatment Technologies for Surface Water and Total Coliform Rules.* Washington, DC: EPA Office of Ground Water and Drinking Water.

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