Executive Summary

Effect of Ozone Dissolution Methods on Disinfection Credit, Bromate Formation, and Operating Cost

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Quick Facts

- It is recommended that, for fine bubble diffusion systems, plants be operated under conditions near design flow to minimize the contact time in the dissolution chamber.
- For sidestream injection systems, it is recommended that the exposure time in the sidestream flow be minimized as much as possible to minimize the ozone exposure and corresponding bromate formation.
- Increasing gas to liquid (G/L) ratio did not impact transfer efficiency for sidestream-without-degas. However, it reduced the transfer efficiency during sidestream-with-degas.
Overview

Ozone systems commonly use either fine bubble diffusion (FBD) or sidestream injection (SSI) for gas-liquid mass transfer of ozone into water. In the early 2000s, SSI emerged as an alternative to FBD due to the ease of accessibility to process components, lack of diffuser maintenance, improved transfer efficiency, and reduced capital costs associated with deep ozone contactors. However, SSI has some limitations, including the operating cost of pumping and the potential for water condensation and nitric acid formation in sidestream components. Most newly constructed ozone systems are now using SSI, and some existing FBD systems have been retrofitted with SSI due to the previously mentioned advantages.

In manuals related to the Surface Water Treatment Rule (SWTR) and Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), the U.S. Environmental Protection Agency (EPA) has provided guidance for calculating disinfection credits for viruses, *Giardia*, and *Cryptosporidium*. The typical contactor configuration in these guidance manuals involves gas-liquid mass transfer in the first dissolution chamber (FBD) followed by ozone exposure (CT) determination in subsequent chambers (disinfection zone). Under this scenario, there is no disinfection credit received for ozone exposure in the bubble column (referred to in this study as Dissolution CT). The significance of Dissolution CT in full-scale treatment has not been extensively studied. Similar guidance can be used for SSI systems with degas, where disinfection CT credit can be calculated beginning at the point of blending the sidestream flow with the full water flow. Differences between these methods of ozone dissolution (FBD or SSI) were found to have a significant effect on ozone disinfection credit and bromate formation at the Regional Municipality of Halton. During an investigation of three full-scale treatment facilities operated by Halton, the SSI facility provided greater CT and less bromate compared to the two FBD facilities when operated under similar ozone dose conditions.

The full-scale observations at Halton prompted more questions regarding the design and operation of both FBD and SSI systems. Ozone industry experts determined that further investigation of several design and operation issues at pilot-scale was warranted, which resulted in this study. Pilot-scale testing of FBD was recommended to further investigate the significance of Dissolution CT and corresponding bromate formation under counter-current and co-current flow conditions. Pilot-scale testing of SSI systems was recommended to further investigate the effect of design (e.g., gas to liquid ratio, pressure, contact time, ozone concentration) and water quality (i.e., bromide) parameters on mass transfer efficiency and bromate formation in the sidestream and blended flow. The results are intended to further the understanding of design and operation of the systems by design engineers and utilities.

Fine Bubble Diffusion (FBD) Systems

At design flow, FBD systems are typically designed so the first contactor chamber has 1-3 minutes of contact time and a diffuser depth of around 18-22 ft, resulting in a hydrostatic pressure of around 10 psi. However, full-scale plants are rarely operated at design flow. If parallel contactors are not taken out of service, the contact time increases in the dissolution chamber. This operating condition can result in higher detention time in the dissolution zone, resulting in significant ozone exposure and bromate formation that are not considered in the regulatory CT calculation for disinfection.

Pilot-scale results showed that ozone exposure (0.31 mg-min/L) and bromate formation (0.8 μg/L) are minimized in the dissolution chamber when operating at design flow (25 gpm, t=2 min). When reducing the flow rate to 10 gpm and 6 gpm, the contact time increased to 5 min and 8.5 min, respectively. The reduction in flow increased the Dissolution CT to 1.45 and 2.85 mg-min/L and bromate formation to 5.6 and 9.1 μg/L, respectively. Similar results were observed whether the contactor was operated under counter-current or co-current flow conditions. Testing was also completed to investigate the effect of bubble size on ozone mass transfer. Results showed no significant differences between bubble diameters of 2 and 15 μm.
Under the EPA guidelines for determining disinfection credit, CT in the dissolution chamber is not included in the CT value for compliance. Therefore, the following is recommended for FBD systems:

- Operate the plant under conditions near design flow to minimize the contact time in the dissolution chamber.
- Consider taking parallel contactors out of service in order to minimize the contact time in the dissolution chamber.

**Sidestream Injection (SSI) Systems**

Pilot-scale testing of SSI systems (with and without degas separation) was performed to investigate the effect of various design and water quality parameters on mass transfer efficiency and bromate formation. The following conclusions were made from the pilot-scale results.

- Increasing gas to liquid (G/L) ratio did not impact transfer efficiency for sidestream-without-degas (SSIwo-dg), likely due to mass transfer occurring at both the venturi and pipeline flash reactor (PFR). Dissolved ozone residuals increased after blending the sidestream with the full flow at greater G/L ratios, indicating that more transfer is taking place at the PFR.
- Increasing G/L reduced the transfer efficiency during sidestream-with-degas (SSIw-dg), likely due to mass transfer occurring only at the venturi.
- The dissolved oxygen (DO) concentration following SSIwo-dg (20 mg/L) was greater than SSIw-dg (14-17 mg/L).
- Bromate formation remained below 10 μg/L in the sidestream when operating with either SSIwo-dg (sidestream ozone dosages up to 10 mg/L) or SSIw-dg (sidestream ozone dosages up to 18 mg/L). After blending with the full-flow, the contribution of bromate was <2 μg/L under the conditions tested.
- Water pressure downstream of the injector did not appear to impact transfer efficiency (TE) under the conditions in this study. However, water pressure upstream of the injector did appear to impact transfer efficiency during both SSIw-dg and SSIwo-dg. The decrease in TE with reduced injector upstream pressure was more apparent in SSIw-dg. Upstream pressure was reduced from 60 psi to 35 psi.
- Increasing water pressure from 1 to 12 psi at the point of blending (i.e., PFR) increased the dissolved ozone residual up to 0.70 mg/L.
- Increasing the ozone feed gas concentration (6-13%) did not appear to impact the transfer efficiency in either SSIwo-dg or SSIw-dg. However, all other operating parameters were kept constant during pilot testing (e.g., G/L ratio), which is likely not the case in full-scale installations. In full-scale systems, increasing ozone concentration will reduce G/L ratio, and reduction in G/L ratio did result in an improvement in TE.
- Increasing the raw water bromide concentration from 70 to 170 μg/L resulted in nearly double the amount of bromate formation in both the sidestream flow and blended flow.
- A contact time of up to 10 minutes was simulated in the sidestream flow using a batch reactor. Results showed that bromate formation can be significant if exceeding the design recommendation of <5 seconds in the sidestream flow.

The following is recommended for SSI systems:

- When operating SSIwo-dg at lower G/L ratios (<0.10), the majority of mass transfer occurs at the injector and less mass transfer is required at the flash reactor.
- When operating SSIwo-dg at higher G/L ratios (>0.10), mass transfer occurs at the injector; however, additional mass transfer is required when combining the sidestream with full water flow (e.g., pipeline flash reactor) to achieve high transfer efficiency.
- When high mass transfer is achieved in SSIwo-dg at higher G/L ratios (>0.10), then greater initial residuals may exist entering the disinfection zone for potentially greater “Compliance CT.”
- Increasing the water pressure upstream of the venturi may improve ozone mass transfer efficiency.
• Increasing the water pressure at the point of blending (i.e., PFR) may improve mass transfer efficiency when operating with SSi\textsubscript{Wo-dp}. Equally, or probably more, important is the need for good mixing in the full-flow in order to develop small bubbles that are necessary for ozone transfer at that location.

• Minimize the exposure time in the sidestream flow as much as possible to minimize the ozone exposure and corresponding bromate formation. (Note: typical design of sidestream flows is less than 5-6 seconds).

### Related WRF Research

- Role of Bromamines on DBP Formation and Impact on Chloramination and Ozonation, project #4159
- Bromate Disposition and Mechanisms of Toxicity at High and Low Doses, project #4042
- Use of Membrane Contactors for the Diffusion of Ozone, project #2885
- Improvement of the Ozonation Process Through the Use of Static Mixers, project #2537