Pilot-Scale Investigation of Transfer Efficiency in Sidestream Ozone Systems

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Abstract

Many surface water treatment plants utilize ozone to meet a variety of water quality and treatment objectives including disinfection and the oxidation of inorganic and organic contaminants. Disinfection guidelines for ozone have been defined by the USEPA Surface Water Treatment Rule and Long Term 2 Enhanced Surface Water Treatment Rule largely based upon ozone dissolution using fine bubble diffuser (BD). Since the development of the USEPA guidance manuals, sidestream injection (SSI) has emerged as a viable alternative to BD for ozone dissolution. The study will discuss the results from Water Research Foundation project 4588 with focus on ozone mass transfer efficiency in sidestream ozone systems.

1. INTRODUCTION

This research study was designed to aid with the identification of the design, operating, or water quality factors creating these differences in bromate formation. Factors such as temperature, ozone dose, initial residual, CT, *Cryptosporidium* log inactivation, and time have been evaluated with no direct correlation explaining the differences in bromate formation (Rakness et al. 2012, Mundy et al. 2013, Mundy et al. 2014). The primary objective of the pilot testing was to replicate the differences in bromate formation using BD, SSI with de-gas, and SSI without degas.

When investigating ozone exposure and bromate formation, it is important to understand where the disinfection zone begins to determine the "Compliance CT". In BD systems, this zone often begins in the chamber immediately following the bubble diffusion cell (Figure 1). However, there could be significant ozone CT occurring in the first chamber where the bubble diffusers are located, which is referred to as "Dissolution CT" in this document. The overall "Exposure CT" is equal to the sum of "Dissolution CT" and "Compliance CT".

In sidestream injection systems, the "Compliance CT" begins upon mixing the sidestream flow with the full process flow (Figure 2). The "Dissolution CT" includes the ozone sidestream flow, which contains a high dose of ozone for short duration until blending with the full process water flow. Again, the overall "Exposure CT" would be equal to the sum of "Dissolution CT" and "Compliance CT".

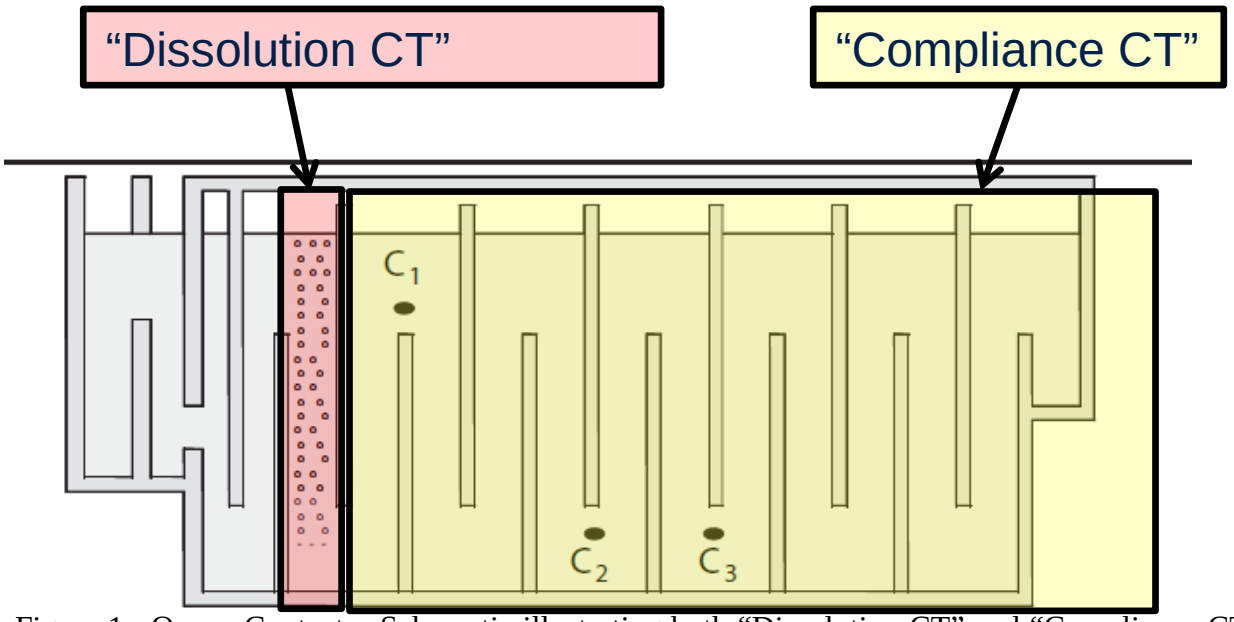

Figure 1. Ozone Contactor Schematic illustrating both “Dissolution CT” and “Compliance CT” in a Fine Bubble Diffusion System.

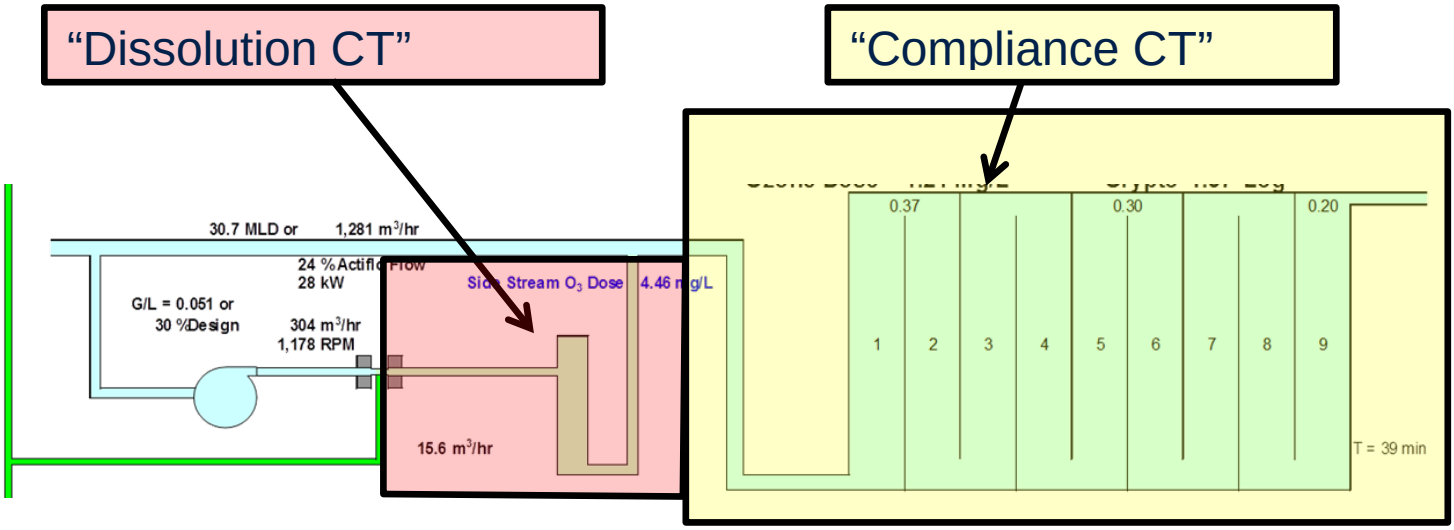

Figure 2. Ozone Contactor Schematic illustrating both “Dissolution CT” and “Compliance CT” in a Sidestream Injection System.

2. MATERIALS AND METHODS

Pilot-scale testing was conducted at the Southern Nevada Water Authority (SNWA). Raw water from Lake Mead was used to conduct the pilot-scale testing. The pilot facilities included a side stream injection system with and without degas with a flow rate of 25 gpm. The side stream injection skid was built by SNWA staff, with two injectors, a pipeline flash reactor, and degas vessel provided by Mazzei Injector Company (Figure 3). The top flow path shows the side stream with injector 584 and degas vessel. The middle flow path is the side stream flow with injector 484 without degas vessel. The bottom flow path is the main stream and shows the pipeline flash reactor with opposing and alternating nozzles. During sidestream with degas, the concentration of the off-gas was measured by an online monitor. The off-gas concentration was used to calculate the transfer efficiency. The sidestream flow was blended with the total in the pipeline flash reactor (PFR) using opposite facing injection nozzles.

A 25-gpm column was used to transfer ozone via fine bubble diffusion. Ozone gas was diffused through a stone diffuser at the bottom of the chamber and was transferred counter-currently into the water. The ozone feed gas rate for the study was 2 slpm. Visual observation indicated a well distributed bubble pattern. A 25-gpm ozone contactor was constructed to provide 2 minutes of contact time. The contactor can be operated in counter-current mode with BD or as an upflow contactor to provide the desired contact time after the SSI. The contactor is equipped with ten sample ports at various sample depths to allow profiling. Following ozone mass transfer by either SSI or BD into 25 gpm, the flow was split with 6 gpm directed to a pilot-scale ozone contactor and 19 gpm sent to waste. The ozone contactor consists of 12 PVC cells, each of which provided 2 minutes of contact time, for a total contact time of 24 minutes at the design flow rate (Figure 4). Sampling ports are located at the top, middle, and bottom of each cell to facilitate contactor profiling and sampling. The ozone off-gas was collected into a central manifold and sampled to measure the concentration (model H1-LR, IN USA Inc., Needham, MA). Additional information regarding these system can be found elsewhere (Wert et al. 2014).

Figure 3. Pilot-scale side stream injection systems

3. RESULTS

Pilot testing was conducted to compare ozone exposure and bromate formation at 3 different water flow rates during BD. The flow rates tested were 25 gpm, 10 gpm, and 6 gpm using the pilot plant configuration. Dissolved ozone residual and bromate formation were measured at each sampling location over the column depth. The transferred ozone dosages were between 1.7-1.9 mg/L during the testing. Ozone exposures were calculated based upon a triangle area under the dissolved ozone residual curve. The following CT values were calculated for flow rates of 25-gpm (CT=0.34 mg-min/L), 10-gpm (CT=1.5 mg-min/L), and 6-gpm (CT=3.4 mg-min/L). These CT values would not be included when determining ozone disinfection credit because regulations do not allow CT credit in the first ozone dissolution cell.

Operating a BD contactor at flow rates below the design water flow rate has impact on bromate formation. At lower water flow rates, greater contact time occurs in the initial diffusion chamber allowing more time for bromate formation. In this case, bromate formation was measured as follows for different flow rates: 25-gpm (BrO_3=0.7 µg/L), 10-gpm (BrO_3=3.7 µg/L), and 6-gpm

(BrO3=5.3 µg/L). This bromate formation would occur prior to receiving any formal CT credit from the ozone process which begins at the outlet of the first diffusion cell.

Regarding transfer efficiency, the sidestream injection system without degas experienced transfer efficiency greater than 94% over a G/L ratio range of 0.1-0.2. The high mass transfer efficiency was likely related to mass transfer following injection and additional mass transfer occurring in the pipeline flash reactor. At greater G/L ratios, there appeared to be less transfer at the injector and greater transfer at the pipeline flash reactor resulting in greater initial dissolved ozone residuals.

Sidestream injection with degas experienced a reduced transfer efficiency from 93% to 76% as the G/L ratio increased from 0.03-0.12. The reduced transfer may be the result of faster coalescence in the pipe following the injector. In addition, there was approximately 0.68 seconds between the injector and degas separator.

4. Conclusions

- Differences in bromate formation appear to be attributed to the defined disinfection zone associated with each ozone dissolution method. Differences between the design and operating water flow rate also appear to play a role in bromate formation during ozone dissolution with BD.
- Based on the pilot studies, bromate formation appears to be equivalent when operating the three ozone dissolutions system at the design water flow rate. The ozone dose produced similar measured CT for equivalent ozone dosages.
- The potential exists for elevated bromate concentrations in BD systems when operating below the design water flow rate due to ozone exposure in the bubble column that is not included in the regulatory determination of ozone CT. Pilot results showed that bromate formation increased from 0.7 to 3.6 µg/L when increasing the contact time from 2 to 5 minutes in cell #1 (bubble diffusion cell).
- Systems that minimize initial ozone exposure, such as side stream, will produce less bromate when compared to significant initial ozone exposure times associated with BD systems at low water flow rates.
- Design considerations for BD plants would be to minimize initial exposure times as much as possible in the ozone dissolution chamber.

5. Recommendations

- Future research will focus on comparing “dissolution CT” and “compliance CT” as part of Water Research Foundation project 4588 titled “Effect of Ozone Dissolution Methods on Bromate Formation, Disinfection Credit, and Operating Cost”

6. Acknowledgements

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