Synergies of UV Disinfection and Ozone in Water Treatment

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Abstract

Two case studies outlining the benefits of using ozone and UV are presented in this paper. They demonstrate the cost effectiveness and robustness that can be observed when the synergies of these two treatment alternatives are utilized. In the first study, ozone and UV disinfection were used at the Weber Basin Water Conservancy District's Water Treatment Plant No. 3. The ozone system was designed to improve pretreatment, control taste and odor (T&O) compounds, and provide an additional *Giardia* barrier, while UV was used to provide 2-log of *Cryptosporidium* inactivation. The capital cost savings obtained by using this option, as opposed to using ozone alone, were nearly 50%. In the second study, the effectiveness of ozone and UV were assessed on the challenging water of Lake Okeechobee. With the goal of meeting all US Primary and Secondary Drinking Water Standards, the data analysis indicated that a combination of ozone and UV disinfection would result in the most cost-effective option. The use of ozone to reduce color and decrease UV transmittance (UVT) resulted in substantial cost savings by decreasing the ozone dose over what would be required to achieve *Cryptosporidium* disinfection and allowing for the elimination of an ozone contactor. Furthermore, the increase in UVT that was observed resulted in a smaller UV system, thereby reducing the cost of the overall system even further.

Keywords
Cryptosporidium; ozone; synergy; UV disinfection; UV transmittance

INTRODUCTION

Ozone is widely used in the drinking water treatment industry to meet multiple treatment objectives, including: disinfection, T&O removal, color removal, iron and manganese control, and removal of organic matter (when combined with biologically active filters). It is well known that ozone is effective for the inactivation of *Cryptosporidium*; however, the ozone dose required to achieve a given inactivation is dependent on water quality and especially temperature. The CT required to achieve 2-log of *Cryptosporidium* inactivation increases by a factor of approximately 10 as the temperature decreases from 20°C to 1°C (Rennecker et. al., 1999). Disinfection with ultraviolet (UV) light is an emerging technology for *Cryptosporidium* inactivation. This paper discussed process synergies that were observed in two studies when using both ozone and UV processes in the treatment train to achieve long-term regulatory compliance.

WEBER BASIN WATER TREATMENT PLANT NO. 3

Weber Basin WTP No. 3 was a conventional WTP that used GAC and disinfection with free chlorine. In planning for the expansion from 26 mgd to 46 mgd, the following process alternatives were considered: low-pressure membrane filtration, ozone disinfection (with a hydraulic residence time of 30 minutes and a CT of 15 mg/L-m), UV disinfection with a dosage of 50 mJ/cm^2, and the combination of ozone and UV processes. Process selection was driven by a regulatory analysis in which criteria for compliance with existing and future regulations were developed. These criteria included achieving compliance with existing regulations for *Giardia* and virus inactivation, and for anticipated regulation requiring *Cryptosporidium* inactivation/ removal. In addition, goals were established for THMs and HAA-5 at 40μg/L and 30 μg/L, respectively, and a finished water turbidity goal of 0.07 NTU. Criteria was also established for secondary regulations, such as taste and odor. Initially, the process recommendation was to select ozone to meet the multiple treatment objectives. By doing so, the plant would be able to provide for the following:

- T&O control
- Improvement of DBP precursor removal when used in conjunction with biologically active filters
- Eliminate the need for GAC
- *Cryptosporidium* inactivation

Initial design criteria were developed which indicated that a hydraulic retention time (HRT) of 30 minutes and a CT of 15 mg min/L would be sufficient to provide for 2-log *Cryptosporidium* inactivation at 2°C. However, subsequently published literature indicated that the inactivation of *Cryptosporidium* was more challenging and that an HRT of 40 minutes and a CT of 38 mg min/L would be required at 2°C. These revised design criteria effectively doubled the capital cost of the ozone facilities and subsequently made the ozone alternative a less feasible option. Based on this development, the feasibility of ozone and UV in the process train was evaluated. Using this concept, the goals for ozone were:

- T&O control
- Additional *Giardia* barrier
- Improved pre-treatment with the use of pre-ozonation

In contrast, the treatment goal for UV disinfection was to provide 2-log of *Cryptosporidium* removal.

Based on this treatment alternative, new cost estimates were developed. The cost estimate for the ozone and UV option are compared to the cost estimates for ozone alone in Table 1.

Table 1 Cost Estimates for *Cryptosporidium* Inactivation Alternatives

	[1]Ozone – 2 Log	**UV – Log/Ozone –T&O**
Capital Cost	$8,100,000	$4,600,000
O&M Cost ($/1000 gallons)	$0.08	$0.01
[2]Annual O&M Cost	$460,000	$60,000

[1] Based on Low Temperature Data (1°C) Developed by Dr. Gordon Finch
[2] Based on 15 MGD Average Daily Flow

In the alternatives analysis, a number of benefits of the ozone/UV process combination were identified. These included:

- The ozone/UV combination provides multiple barriers for *Cryptosporidium* and *Giardia*
- Ozonation increases the UV transmittance of waters and thereby reduces operating and capital costs of the downstream UV system
- Disinfection efficiency of UV light is not strongly temperature dependent and offers additional disinfection credit at lower water temperatures
- UV provides a disinfection against sloughed biofilm from biologically active filters

Based on the cost effectiveness and the benefits listed above, the Weber Basin Water Conservancy District selected the ozone and UV disinfection option. The plant expansion design has been completed and construction is expected to be finished sometime in 2003.

CERP ASR PILOT STUDY

Carollo Engineers was selected by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD) to conduct a pilot study as part of their Comprehensive Everglades Restoration Project (CERP). CERP is an $8 billion project designed to capture freshwater from Lake Okeechobee, that would otherwise be diverted to the ocean through canals, and direct it back into the Everglades ecosystem for restoration. This particular project evaluated potential options to treat Lake Okeechobee water for an aquifer storage and recovery (ASR) program that will ultimately include over 300 wells with an ultimate treatment capacity of over 1.5 billion gallons per day (bgd). During dry months, this water will then be pumped from the ASR wells and directed back to the Everglades.

Given the challenging water quality characteristics of Lake Okeechobee (Table 2), Carollo Engineers, in collaboration with ASR Systems, University of South Florida, and EET, proposed the use of bank filtration followed by ozonation and/or UV disinfection to meet the requirement of all U.S. Primary and Secondary Drinking Water Standards. This unconventional treatment train was selected because it produces no residuals, has little (if any) chemical requirements, and offered a multiple barrier approach to pathogen control.

Table 2 Summary of Non-Biological Raw Water Quality

Parameter	Average	Min	Max
Turbidity (NTU)	15.5	5.4	57
Dissolved Oxygen (mg/L)	6.0	3.3	6.9
Color (Apparent)	263	194	>520
Color (True)	96	30	235
Hardness (mg/L as $CaCO_3$)	153	90	209
TSS (mg/L)	16.2	7.2	56
TOC (mg/L)	27	21	27

Table 2 Summary of Non-Biological Raw Water Quality

(continued)

Parameter	Average	Min	Max
DOC (mg/L)	21	17.7	32.3
UV Absorbance (Unfiltered)	0.750	0.540	0.975
UV Absorbance (Filtered)	0.640	0.419	0.900
Alkalinity (mg/L as $CaCO_3$)	107	60	136
Bromide (mg/L)	210	150	280
TDS (mg/L)	318	240	380
Conductivity	533	302	725
Iron (mg/L)	0.150	0.082	0.224
PH	7.9	7.3	8.5

The pilot process train consisted of a simulated bank filtration system where the filter effluent was directed to two parallel processes: ozonation and UV disinfection (an Aquionics medium pressure system). Near the end of the study, the system was reconfigured to test ozonation and UV disinfection in series.

An analysis of the data was performed and the results indicated that due to the treatment requirements, a system comprised of both ozone and UV disinfection would result in the most cost-effective solution. This conclusion was due, in part, because of the high organic content of the Lake Okeechobee water. Pilot testing indicated that the oxidant demand of the water was so large as to render disinfection with ozone impractical. Furthermore, the high UV transmittance (UVT) of the water would require the use of large UV systems, resulting in a prohibitively expensive disinfection process. As a result, cost estimates were developed based on an ozone and UV disinfection system that would use the advantages of both technologies to address the regulatory requirements of the project. In order to accomplish this in a cost-effective manner, the ozone system would be designed to treat the high color of the water and to increase UVT, thereby resulting in a smaller and less expensive UV system required to meet the disinfection challenges. The use of ozone in this way resulted in a smaller ozone system, in addition to eliminating the need for an expensive ozone contactor, since long HRTs would not be required to obtain disinfection credit using ozone.

Cost estimates based on the transferred ozone dose were determined from quotes provided by the equipment suppliers. The estimates are provided in Table 3.

Table 3 Capital, Production, and O&M Costs Associated With an Ozone and UV System

Transferred Ozone Dose (mg/L)	**0.98**	**2.52**	**5.46**	**10.92**
Capital Cost	$2,700,000	$2,600,000	$2,600,000	2,750,000
O&M Cost ($/1000 gal)	$0.15	$0.11	$0.11	$0.11
O_3 and UV Production Cost ($/1000 gal)	$0.61	$0.55	$0.53	$0.56

Note: The cost estimates assumed a medium-pressure system and a dose of 140 mJ/cm^2. The cost of an ozone contactor was not included, since disinfection was not a goal of the ozone system.

CONCLUSIONS

The synergies of ozone and UV disinfection result in a robust treatment process that is capable of treating a wide range of water quality issues and meeting multiple regulatory requirements. In addition, the complementary mechanisms of each process can result in significant savings in both capital and operation and maintenance (O&M) costs when they are designed to meet a particular goal. At the Weber Basin Water Conservancy District's WTP No. 3, these synergies were exploited to result in an approximate 50% savings, when compared to the use of ozone alone. This was achieved through the design of a smaller ozone system to treat T&O compounds, improve pretreatment and serve as a barrier to *Giardia*. In contrast, the UV disinfection system was designed to obtain the required *Cryptosporidium* inactivation credit.

Similarly, the advantages of ozone and UV disinfection were observed in the CERP ASR project. The high organic content of Lake Okeechobee translated into a high-colored water, with low UVT and a very high oxidant demand. These characteristics precluded the use of either ozone or UV alone to meet the desired finished water quality goals. The results of the study indicated that optimal treatment and reduced cost would be observed by using both ozone and UV disinfection. Sizing of the ozone system to decrease the color of the water and increase the UVT resulted in substantial capital and O&M savings by decreasing the size of the ozone system, eliminating the need for an ozone contactor, as well as reducing the size of the UV disinfection system.

REFERENCES

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