

Efficacy of Ultraviolet Advanced Oxidation in a Drinking Water Utility with Full-Scale Granular Activated Carbon Adsorption

Deborah H. Metz^{1,2}, Maria Meyer¹ and Ramesh Kashinkunti¹ Erwin F. Beerendonk³

¹Greater Cincinnati Water Works, 5658 Kellogg Ave., Cincinnati, OH, 45228,

²University of Cincinnati, Dept. of Civil & Environ. Engineering, 765 Cincinnati, OH 45221,

³KWR - Watercycle Research Institute, PO Box 1072 3430 BB, Nieuwegein, The Netherlands

ABSTRACT

A year-long UV/H₂O₂ study was conducted using a 208-L/min (55-gpm) pilot plant to degrade pharmaceutical and other organic contaminants in drinking water. Two surface water process streams of differing organic content were used in the study, and UV doses were based on the 80 percent degradation of atrazine and 55 percent degradation of methyl tert-butyl ether. The energy required to degrade each contaminant varied. Less energy was required by the low pressure than the medium pressure lamp. UV/H₂O₂ followed by GAC reduced all contaminants below detection limits. GAC without UV/H₂O₂ also produced excellent results with over 300 run days.

Key Words: advanced oxidation, UV, UV/H₂O₂, GAC, pharmaceutical degradation, MTBE degradation, MIB degradation, pesticide degradation

INTRODUCTION

Direct ultraviolet photolysis (DUVP) and ultraviolet hydrogen peroxide (UV/H₂O₂) processes have the potential to degrade a wide-range of organic micro-pollutants in water with varying effectiveness. Greater Cincinnati Water Works (GCWW) is designing a 908,500-m³/d (240-MGD) ultraviolet (UV) disinfection facility for a drinking water plant that treats Ohio River water. GCWW additionally wished to determine the efficacy of UV/H₂O₂ for reducing pharmaceuticals and other organic contaminants. Therefore, GCWW developed a comprehensive UV master plan to evaluate the potential benefits of converting the UV disinfection facility into a UV/H₂O₂ facility. As part of the master plan, GCWW joined a Dutch/U.S. collaboration to determine if low pressure (LP) and medium pressure (MP) UV/H₂O₂ processes could effectively degrade micro-pollutants in conventionally treated and granular activated carbon (GAC) treated process streams. GAC has long been considered an excellent technology for removing a broad spectrum of organic contaminants, particularly hydrophobic compounds. However, breakthrough of contaminants occurs as the GAC becomes exhausted, and hydrophilic compounds break through the GAC more quickly than hydrophobic compounds. A year-long UV/H₂O₂ study was conducted that examined a variety of seasonal and GAC breakthrough conditions. This pilot plant study was performed at GCWW's Ohio River plant.

MATERIALS, METHODS AND FACILITIES

The study was conducted using a 208-L/min (55-gpm) pilot facility with Aquionics LP and MP reactors. Two drinking water process streams were used to reflect a moderate organic process influent and a low organic process influent each having seasonal variations. The UV transmittance (UVT) of the GAC treated (Post-GAC) process stream ranged from 94-98% as compared to 84-95% for the conventionally treated (CONV) process stream. Therefore, it was hypothesized that the UV/H₂O₂ degradation process would be more effective when the Post-GAC process stream was used as reactor influent. The pilot process also included adsorption through 0.95-L/min (0.033 ft³/min) GAC pilot columns (15 min. empty bed contact time) placed after the UV reactors in order to provide a barrier against synthetic organic contaminant degradation by-products, disinfection by-product precursors and biologically available carbon (**Figure 1**). Thus, both lamp technologies were studied for both the CONV and Post-GAC process streams.

GAC adsorption varies with hydraulic loading and the organic content of the GAC influent stream. Natural organic matter contributes more significantly to GAC exhaustion than synthetic contaminants. Accordingly, this study was performed over a year-long time period to reflect seasonal variations and multiple GAC loading conditions. The TOC breakthrough curve is included as a measure of GAC exhaustion during the study (**Figure 2**).

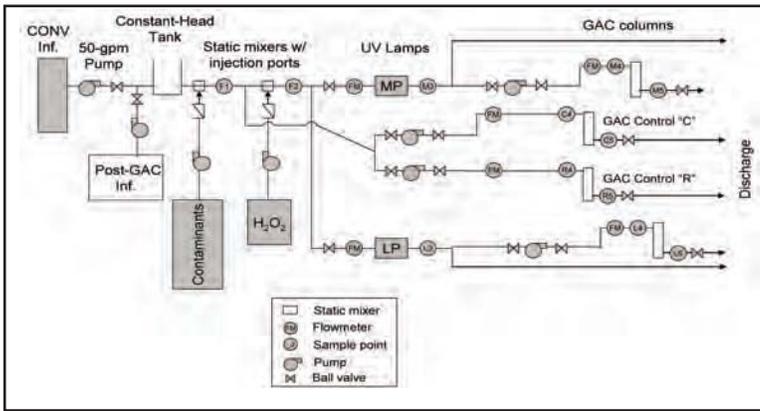


Figure 1: Pilot Plant Schematic

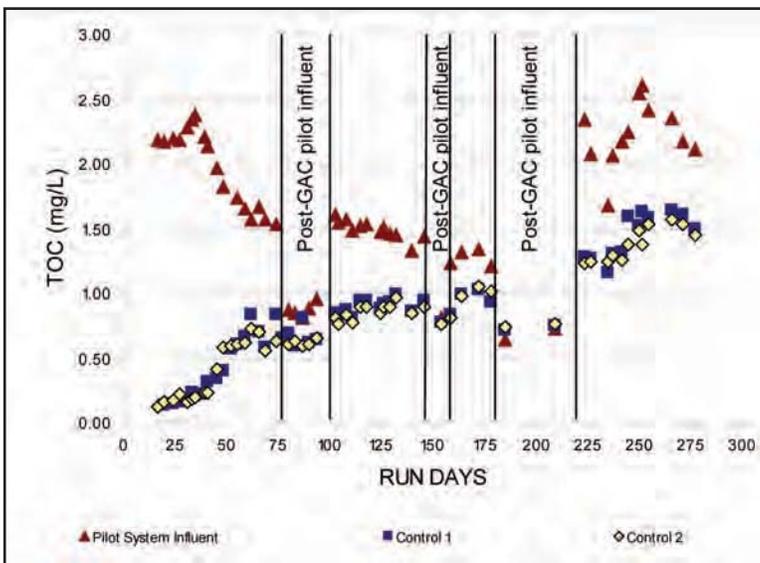


Figure 2: TOC Removal by GAC Reflective of GAC Exhaustion

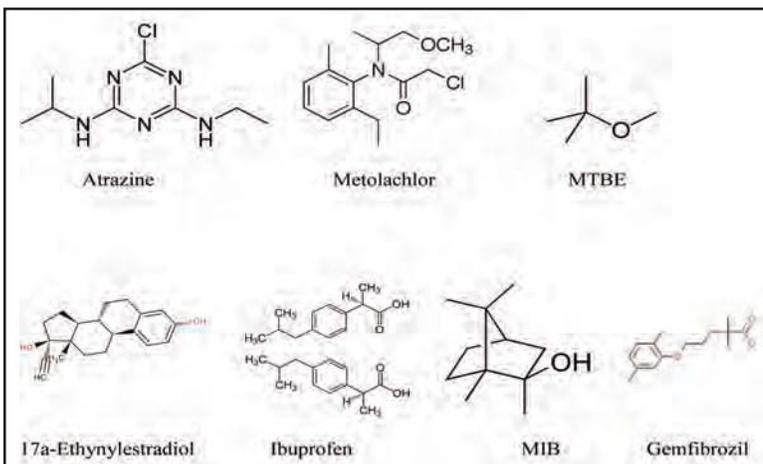


Figure 3: Spiked contaminants

Contaminants were selected based on Ohio River detections, chemical structure of the contaminants and bench-scale test results for UV/H₂O₂ and DUVP. The contaminants spiked into the pilot influent were atrazine, metolachlor, methyl tert-butyl ether (MTBE), 2 methylisoborneol (MIB), ibuprofen, gemfibrozil, and 17-a-ethinyl estradiol (Figure 3). The concentrations of spiked contaminants were chosen to be realistic of drinking water sources and to be able to determine percent degradation through the reactors (up to 90%). Preliminary mixing and spiking studies were performed to insure that contaminant spiking targets were met.

Hydrogen peroxide was added at 10 mg/l, and the UV reactor doses were set to target 80% atrazine and 55% MTBE degradation. Often times UV/H₂O₂ technologies have been compared using comparable doses or comparable energy consumption, but this study utilized a performance-based measure of comparison. This approach allowed biologically active carbon formation and disinfection by-products to be evaluated by comparing systems that would produce comparable degradation performance.

RESULTS AND DISCUSSION

Good degradation of test contaminants was achieved for the UV/H₂O₂ process when 80% atrazine and 55% MTBE degradation were targeted (Table I). The energy consumption required to degrade each contaminant varied for the UV/H₂O₂ process. Energy consumption additionally was governed by the process stream and the lamp type. Less energy was required for the Post-GAC process stream than in CONV process stream. Less energy was required by the LP reactor versus the MP reactor. UV/H₂O₂ followed by GAC reduced all contaminants below detection limits. GAC without UV/H₂O₂ (control) also produced excellent results with over 300 run days. None of the target compounds were present in the GAC effluent until run day 286. At 286 days MTBE alone was detected in the GAC effluent at a concentration of 0.3 µg/l, representing a 94 percent reduction of MTBE (Table II).

Good reduction of TOC, disinfection by-products and assimilable organic carbon compounds occurred through the biologically active GAC that followed the UV reactors. This indicates that the GAC also would provide a barrier to the contaminant breakdown products formed in the UV/H₂O₂ process. Additionally, the GAC completely quenched the H₂O₂ residual (averaging 8.9 to 9.2 mg/l) throughout the course of the study. It is important to quench the GAC because it can create a high chlorine demand thereby reducing disinfection ability and chlorine residual in the distribution system.

GCWW's full-scale UV disinfection facility will include flexibility to install UV/H₂O₂ in the future. For example, the current building footprint is adequate to

incorporate either the low pressure (LP) or the medium pressure (MP) type lamps. Sufficient reactor spacing is available to add additional reactors in series and parallel, including additional UV lamps. For the CONV option, an existing intermediate pump station would need to be relocated. For the Post-GAC option, re-pumping also may be required in order to maintain the required driving head. Residual peroxide quenching would also need to be considered for this option.

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Table I: Average Percent Contaminant Degradation through UV/H₂O₂ Process at 80% Atrazine and 55% Methyl tertiary butyl ether Degradation

	Metolachlor	MIB ¹	EES ²	Gemfibrozil	Ibuprofen
LP CONV Process Stream	93%	87%	93%	92%	82%
MP CONV Process Stream	96%	90%	98%	92%	87%
LP Post GAC Process Stream	95%	91%	96%	95%	84%
MP Post-GAC Process Stream	95%	88%	94%	93%	85%

1. 2-methyl-isoborneol
2. 17-a-ethynylestradiol

Table II: Contaminant Monitoring through GAC Controls and MP and LP UV/H₂O₂ Process Trains Followed by GAC



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GAC Effluent Concentrations								
GAC Runday	GAC Eff. Type	Atrazine	Metolachlor	MTBE ¹	MIB ²	EES ³	Gemfibrozil	Ibuprofen
35	Medium Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
35	Low Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
35	Control 1	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
35	Control 2	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
126	Medium Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
126	Low Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
126	Control 1	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
126	Control 2	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
173	Medium Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
173	Low Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
173	Control 1	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
173	Control 2	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
286	Medium Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
286	Low Press	<0.1 µg/L	<0.1 µg/L	<0.2 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
286	Control 1	<0.1 µg/L	<0.1 µg/L	0.31 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L
286	Control 2	<0.1 µg/L	<0.1 µg/L	0.26 µg/L	<2.0 ng/L	<5 ng/L	<0.1 µg/L	<0.5 µg/L

1. methyl tertiary butyl ether
2. 2-methyl-isoborneol
3. 17-a-ethynylestradiol