Novel Applications of Combined Advanced Oxidation Processes and Carbon Adsorption for Water Remediation

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Introduction

Over the last several years, contaminated groundwater has become an increasing concern. The efficient treatment of these waters requires innovative treatment processes which offer the best available technologies. In many cases, the most economical solution has been treatment with activated carbon adsorption processes. Although these processes have proven to be effective in the treatment of a wide range of organic compounds, there are some applications involving mixtures of weakly adsorbable, readily oxidizable contaminants and moderately adsorbable contaminants in high concentration which lend themselves to treatment with combined hybrid technologies involving advanced oxidation processes (AOP) and granular activated carbon (GAC). Typical AOPs which have proven to be synergistic with GAC include: UV/H_2O_2, UV/Ozone, and the Fenton's Process (Fe^{++}/H_2O_2). The hybrid method of choice for this investigation was based upon the groundwater contaminants and focused on GAC/ UV/H_2O_2.

Advanced oxidation processes are those processes which utilize oxidizing agents such as the hydroxyl radical for the decomposition of organic compounds in an aqueous media. The oxidizing agent is generated through the catalysis of an oxidant, typically hydrogen peroxide, with media such as UV light. One method for the production of the hydroxyl radical is the photolysis of hydrogen peroxide, where two radicals are produced from one molecule of hydrogen peroxide:

$$H_2O_2 + h\nu \rightarrow 2 \bullet OH$$

The radical reacts with the organic molecule by abstraction from aliphatic or addition to unsaturated compounds initiating a series of oxidations reactions that result in mineralization to carbon dioxide and water when the reaction is taken to completion.

Typical AOP systems consist of an oxidation chamber which contains of a medium pressure mercury lamp shielded by a quartz sleeve. The contaminated water is pumped into the chamber where hydrogen peroxide is added. UV radiation is emitted by the lamp which initiates the formation of the radical from the hydrogen peroxide molecule. A typical AOP system is shown in figure 1.

AOPs treat a variety of organic compounds including aromatics, alkenes, alcohols, ethers, and ketones. Benefits of AOPs include the destruction of organic compounds without phase transfer. The processes are typically carried out at ambient conditions, and offer treatability for a wide range of contaminant concentrations. Limitations of AOPs involve loss of treatment efficiency for waters containing high concentrations of total organic carbon (TOC), refractory compounds, and UV and radical scavengers.

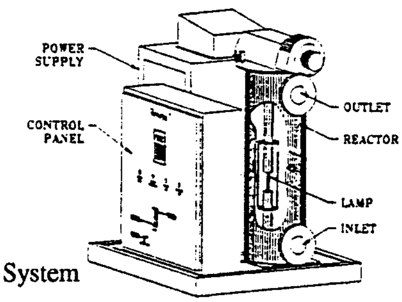

Figure 1. AOP System

Although stand alone AOP and GAC technologies have proven to be effective treatment mechanisms for the removal of various organic compounds from contaminated waters, not all contaminants are successfully treated by one process. Waters containing a mixture of contaminants that are treated more efficiently and economically by either AOP or GAC adsorption lend themselves to hybrid treatment. Case studies representing some hybrid application scenarios have been included.

Results and Discussion

Case study 1 illustrates the benefits of utilizing a hybrid system for treatment of groundwater containing various organic compounds at trace level concentrations and three specific contaminants: dichloroethene (DCE), trichloroethene (TCE), and dichloromethane (DCM). The respective concentrations were 21, 34, and 6.9 ug/L with a treatment objective of 0.5 ug/L.

Treatment options for GAC, AOP, and GAC/AOP technologies were evaluated. The results are listed in the following table:

Case 1 - Groundwater Application

	GAC	AOP	Hybrid (GAC/AOP)
Controlling Contaminant	DCM	DCM	DCE+TCE/ DCM
System Size	8x20,000 lb	8x90 kW	2x20,000 lb/ 4x90kW
Operating Cost($/kgal)	3.10	2.11	1.12
Capital Cost (x$1000)	550	970	700

Comparison between stand alone and hybrid treatment systems indicated a significant difference in system size, operating costs and capital costs required to achieve the desired treatment objective. The hybrid system resulted in an annual operating cost savings of more than 64% and 47% over GAC and AOP stand alone systems, respectively.

Case study 2 illustrates a hybrid system for treatment of groundwater contaminated with vinyl chloride (VC), dichloroethene (DCE), trichloroethene (TCE), dichloroethane (DCA), and trichloroethane (TCA) with respective influent concentrations of 118, 580, 190, 686, and 898 ug/L. The required treatment objective for the compounds was 0.5, 2, 50, 1000, and 200 ug/L, respectively.

The results for GAC, AOP, and AOP/GAC treatment are summarized in the following table:

Case 2 - Groundwater Application

	GAC	AOP	Hybrid (AOP/GAC)
Controlling Contaminant	VC	TCA	TCA/VC
System Size	1x2,000 lb	60 kW	30 kW/ 1x2,000 lb
Operating Cost($/kgal)	7.65	7.56	4.50
Capital Cost (x$1000)	18	134	93
Carbon Changeouts per year	16	N/A	3

Comparison of the data indicated a significant difference in the operating parameters for successful groundwater treatment. The hybrid system resulted in an annual operating cost savings of more than 40% over an AOP stand alone system. In addition, a hybrid system required less maintenance over a GAC stand alone system offering 3 carbon changeouts per year instead of 16.

Case study 3 illustrates treatment of a groundwater operating at a flow rate of 450 gpm. The groundwater contaminants include benzene (1000 ug/L) and dibromoethane (600 ug/L) with respective treatment objectives of 5 and 0.02 ug/L. Treatment options and economics were evaluated for stand alone AOP, and combined AOP/GAC. The results are listed in the following table:

Case 3 - Groundwater Application

	GAC	AOP	Hybrid (AOP/GAC)
Controlling Contaminant	Benzene	Dibromoethane	Dibromoethane/ Benzene
System Size	N/A	1050 kW	180 kW/ 1x20,000 lb
Operating Cost($/kgal)	N/A	3.44	1.55
Capital Cost (x$1000)	N/A	1,300	300

Hybrid treatment resulted in an annual operating cost savings of more than 50% over a stand alone AOP system.

Conclusions

As illustrated by the case studies presented, hybrid treatment combining carbon adsorption technology and advanced oxidation processes offers an efficient and more cost competitive treatment for groundwater contaminated with mixtures of organic compounds that are not readily treatable by either AOP or GAC adsorption alone. The strengths and weaknesses of each technology become complementary when combined to form a hybrid treatment process.

The advantages offered by the hybrid alternative include:

- Increased removal efficiency for certain organic compounds
- Lower operating costs
- Lower costs associated with spent carbon disposal or re-use

The use of the hybrid treatment concept is a technology that is rapidly gaining acceptance as a viable method for groundwater treatment. New developments in this technology are expected to extend the applicability to wastewater applications in the near future.

References

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