



THIS POLICY DOES NOT HAVE THE FORCE OF LAW

Guidelines for evaluating granular activated carbon (GAC) for disinfection by-product (DBP) precursor removal

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This document was developed in consultation with Ohio Section AWWA – Technology Committee for purposes of providing technical guidance to members of the regulated community to comply with disinfection by-product (DBP) maximum contaminant levels and best available technologies for organic contaminants addressed in Ohio Administrative Code (OAC) rules 3745-81-11 and 3745-81-12. Approval of detail plans will be required prior to construction of the proposed granular activated carbon (GAC) facilities, in accordance with Section 6109.07 of the Ohio Revised Code (ORC). Ohio EPA does not have a rule in place to require testing of GAC prior to installation in a water treatment plant (WTP). This document presents a suggested approach for complying with OAC rules 3745-81-11 and 3745-81-12. Nothing herein should be interpreted as precluding other strategies to comply with requirements of the rule.

I. PURPOSE

This document was developed to establish standard protocol for demonstrating the effectiveness of a GAC adsorption system to meet DBP regulatory requirements.

It is intended that successful application of these guidelines will result in design of a treatment system that will meet drinking water requirements at a reasonable cost. GAC treatment of surface water may address removal for a variety of water quality problems such as: taste and odor, color, disinfection by-product (DBP) precursor materials, other organics, synthetic organic chemicals (SOCs) or other contaminants that might be present. This document focuses on GAC treatment for the removal of DBP precursor materials.

II. BACKGROUND AND OBJECTIVES

OAC requires public water systems that use a surface water source to provide treatment to meet the following water quality standards: Primary, Secondary and DBP Standards, and Corrosion Control Requirements (OAC Chapters 3745-81 and 3745-82). GAC technology is a process that can be used to satisfy treatment requirements of the OAC and other treatment objectives. GAC treatment will not satisfy all requirements for the treatment of surface water. The total treatment scheme must be evaluated.

The objective of this guideline is to achieve consistency throughout the State of Ohio in administering provisions of the OAC in regard to the use of GAC systems for compliance with surface water DBP requirements.

Background of DBPs

Total trihalomethanes (TTHM), haloacetic acids (HAA5), bromate and chlorite are the currently regulated DBPs that may be carcinogens. TTHM and HAA5 formation is associated with the use of free chlorine that is added to water to inactivate pathogenic microorganisms (i.e., microbial). The free chlorine interacts with natural organic matter (humic acids, fulvic acids, etc.) present in the source water to form these DBPs. The amount of natural organic matter present is generally quantified as total organic carbon (TOC) using a simple, inexpensive laboratory test.

TTHM and HAA5 formation is proportional to water temperature (i.e., DBP formation increases with increasing water temperature). As such, Ohio Public Water Systems (PWSs) with surface water sources tend to form a greater concentration of DBPs during late spring, summer and early fall. Therefore, the need to remove TOC prior to chlorine addition is more important during these seasons.

Bromate formation is associated with ozone added to inactivate pathogenic microbial, particularly in source waters with a measurable amount of bromide present. Chlorite formation is associated with chlorine dioxide added to inactivate pathogenic microbial (since by-products of chlorine dioxide are chlorite and chlorate).

There are three general means of reducing the formation of DBPs:

- 1) Remove the TOC before adding chlorine or other DBP-forming disinfectants,
- 2) Use an alternate disinfectant (e.g., chloramines) that does not form regulated DBPs (but is not as strong as a disinfectant as chlorine), and
- 3) Management of hydrologic flow and storage to minimize residence time in the distribution system (for more information, please see AWWA Technology Committee White Paper on Distribution System Optimization for Water Quality, 2007, in progress).

In most cases, it is best to remove the TOC rather than switching to an alternate disinfectant. TOC can be removed from water in a number of ways, but the two principal means available to most Ohio PWSs are:

- 1) Physical removal (enhanced coagulation, membranes) and
- 2) Activated carbon adsorption - either with powdered activated carbon (PAC), or more likely GAC.

Data to evaluate the effectiveness of GAC and/or PAC can be readily gathered at the bench scale. Jar testing can be used to evaluate PAC, and the rapid, small-scale column test (RSSCT) can be used to evaluate GAC in a few weeks. RSSCTs provide equal or more data than pilot- or full-scale tests in significantly less time, and are much less costly.

Summary of DBP Regulations

Compliance requirements for the evolving microbial/DBP (M/DBP) regulations are attempting to balance the short-term, acute health effects associated with pathogenic microbials with the long-term, chronic health effects associated with DBPs.

Maximum contaminant levels (MCLs) for the four DBPs included in the Disinfectants/Disinfection By-Products Rule (D/DBPR) are:

Total Trihalomethanes (TTHM)	0.080 mg/L = 80 µg/L
Haloacetic Acids (HAA5)	0.060 mg/L = 60 µg/L
Bromate	0.010 mg/L = 10 µg/L
Chlorite	1.0 mg/L = 1,000 µg/L

Under Stage 1 of the D/DBPR, compliance with the maximum contaminant levels for TTHM and HAA5 is determined by calculating the running annual average (RAA), computed quarterly, of samples from all monitoring locations across the system, 25% of which must represent the maximum residence time of the distribution system.

Under the Stage 2 D/DBP rule, systems may be required to conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with the highest disinfection byproduct concentrations. Beginning in 2012, compliance will then be calculated for samples collected at the monitoring locations with the highest DBPs identified in the IDSE. Compliance will be determined at each monitoring location, referred to as the locational running annual average (LRAA).

Compliance with the maximum contaminant level for bromate is determined by calculating the RAA of samples collected monthly.

Compliance with the maximum contaminant level for chlorite is based on the results of daily routine and follow-up samples.

III. OTHER APPLICABLE GUIDANCE

Great Lakes Upper Mississippi River Board of State Public Health and Environmental Managers. 2003. *Recommended Standards for Water Work* (also referred to as "Ten States Standards"). Health Research Inc., Albany, NY.

USEPA. 1996. *ICR Manual for Bench- and Pilot-Scale Treatment Studies*. EPA 814-B-96-003. Technical Support Division, Office of Ground and Drinking Waters, Cincinnati, Ohio.

Summers, R.S. et al. 1992. *Standardized Protocol for the Evaluation of GAC*. AwwaRF and AWWA, Denver, Colorado.

IV. POLICY

Acceptability of GAC systems for treatment of DBPs at surface WTPs should be determined in accordance with the following procedures. Deviations from these guidelines should be fully justified by documentation demonstrating equivalency acceptable to Ohio EPA.

1.0 GENERAL CRITERIA

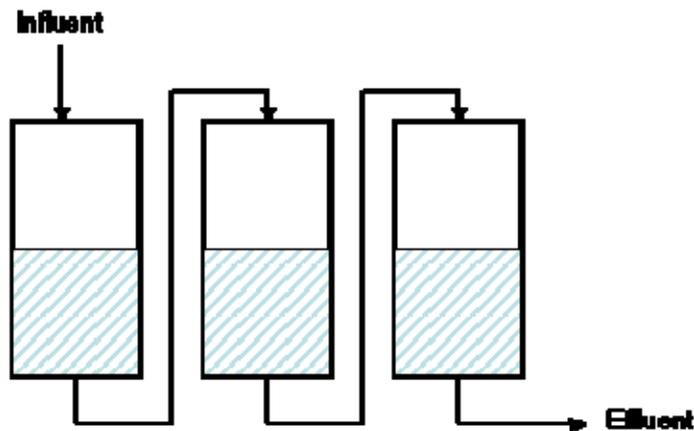
- 1.1. Post-filter, GAC adsorption units provide several advantages compared with GAC/sand, dual-media filters:
 - 1.1.1. Longer empty-bed contact time (EBCT) – i.e., larger media depth.
 - 1.1.2. GAC does not have to be used year round since it is not part of the filters.
 - 1.1.3. Less frequent regeneration/replacement of the GAC. In fact, for many PWSs the GAC can be used during late spring, summer and early fall, then removed from service, regenerated and replaced during the winter; alternately post-filter GAC units can be bypassed by a percentage of the water year round or can be bypassed completely during portions of the year.
 - 1.1.4. Ease of regeneration – i.e., it is nearly impossible to remove the GAC cap for regeneration/replacement due to intermixing of the GAC and sand media at the interface of the two media.
 - 1.1.5. It is recommended post-filter contactors be used rather than replacing or capping the existing filter media with GAC. In addition to the above advantages of post-filter adsorption units, a WTP processing surface water must comply with both: (a) filtered-water turbidity requirements of the surface water treatment rules, and (b) distribution system MCLs for DBPs. It is difficult to operate a dual-media GAC/sand filter optimized for both turbidity and DBP precursor removal. More importantly, GAC/sand dual-media filters are typically optimized for DBP precursor removal, and turbidity removal greatly suffers, leading to potential violations of either the combined or individual filtered-water turbidity requirements. Since the EBCT is small, the GAC cap needs to be frequently removed for regeneration. The portion of GAC media that is intermixed with the sand at the interface (i.e., the larger GAC media) is generally not removed. When the dual-media filter cap is replaced with new or regenerated GAC this material represents the full range of GAC particle sizes. Therefore, with each regeneration the GAC cap consists of larger and larger GAC particles, and the filtering capacity of the cap is compromised with each regeneration. After several regenerations, the L/d ratio (L=GAC media depth and d=GAC media effective size) decreases dramatically. Turbidity removal is proportional to the L/d ratio, and violation of filtered-water turbidity requirements becomes more likely.

1.2. Approval of detail plans will be required prior to construction of the proposed GAC facilities, in accordance with Section 6109.07 of the Ohio Revised Code (ORC). The following design features are recommended. Plan approval will not be denied based on the owner's decision not to incorporate these recommendations into the final plans.

1.2.1. Design of GAC facility with a minimum EBCT of 10 minutes or the time determined from bench- or pilot-scale demonstration studies whichever is greater. Extensive general data available used to generate DBP precursor requirements of the drinking water regulations suggest EBCTs greater than 10 minutes are better. The Stage 1 D/DBP Rule specifies GAC adsorption with an EBCT of 10 minutes as the best available technology (BAT) for achieving compliance with the MCLs for TTHMs and HAA5. The Stage 2 D/DBP rule identifies GAC adsorption with an EBCT of 20 minutes as another BAT. It is highly recommended PWSs collect site-specific data using bench-scale, RSSCTs. It is better to design for an EBCT directly related to the water to be processed, and RSSCTs are easy to conduct in a short period of a few weeks and are cost effective.

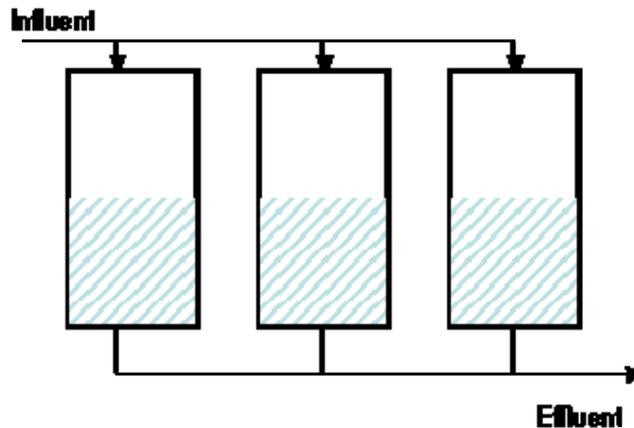
1.2.2. Design of GAC facility should provide piping for either series or parallel flow operation.

1.2.2.1. Operation in series



The first bed in the series will receive the highest loading and will be the first to be exhausted. The final bed in the series acts as a polishing step and receives a very light load. When the first bed is exhausted, it is removed from service, GAC removed and replaced with fresh. The bed would then be placed back into service at the end of the series.

1.2.2.2. Operation in parallel



The start-up of the beds can be staggered so exhaustion of the beds occurs sequentially. The effluent from the fresh and partially exhausted beds can then be blended together to extend the life of the beds.

- 1.2.3. Design of GAC facility should provide for at least two units. This allows treatment to continue while the beds are being backwashed or exhausted GAC is being regenerated and/or replaced. This arrangement also allows the units to be operated in series or in parallel. This flexibility can be advantageous to many small PWSs.

An example is provided in the Appendix for a WTP that has an approved capacity of 1.0 MGD, and an average daily flow of 0.5 MGD. In this small system example a design with two GAC columns provides flexibility and is a more efficient design than three GAC columns. This PWS has two GAC columns, each with a diameter of 12 ft and a media height of approximately 9 ft (i.e., a total reactor height of 15'-4"). This design with two, 12-ft diameter columns has four distinct advantages:

- 1) The two columns provide a total of 2,000 cf of GAC media; which is more than the 1,410 cf of media that would have been provided with a three-column design.
- 2) Each column contains 1,000 cf of GAC media; greater than the 930 cf of media required to provide an EBCT of 10 minutes at the WTP's approved capacity of 1.0 MGD.
- 3) Under normal operating conditions (i.e., average-daily flow of 0.5 MGD), the EBCT would be 21.5 minutes with one unit in-service, or 43 minutes with both units in-service; a better operating arrangement based on results of the RSSCTs that were conducted at the bench scale for this PWS.
- 4) A two, 12-ft diameter column design is more cost-effective for this PWS than a three, 10-ft diameter column design.

- 1.2.4. Design of a GAC facility should provide the ability to backwash the GAC contactors with unchlorinated filtered water. Unchlorinated water should be used since chlorine will be adsorbed onto the GAC and will reduce the life of the bed. It is also recommended the design include the ability to backwash with chlorinated filtered water if the need should arise. Backwashing of the GAC beds is required to reduce headloss due to suspended solids removed within the bed.
- 1.2.5. Design of a GAC facility should provide the ability to filter-to-waste to prevent carbon fines in effluent water. Carbon fines adsorb chlorine and cause an artificial chlorine demand.
- 1.2.6. The owner needs to provide an acceptable means of spent carbon disposal.
- 1.2.7. Design of a GAC facility should provide the ability to bypass the GAC contactors if necessary. It is recommended the empty GAC contactors be disinfected before putting the GAC system on-line.

2.0 DEMONSTRATION STUDY CRITERIA

- 2.1. Prior to the performance of demonstration study, a plan should be submitted to Ohio EPA for review. The plan should include:
 - 2.1.1. Results from analysis of raw and filtered water quality data for the previous 12-month period, particularly DBP-precursor data if available.
 - 2.1.2. Statement of objectives and conclusions from evaluation of the raw and filtered water quality to identify critical conditions to be evaluated during the demonstration study.
 - 2.1.3. Schematic drawings and detailed descriptions of the demonstration study facilities to be used.
 - 2.1.4. Mode(s) of operation to be tested.
 - 2.1.5. Time schedules for each mode of operation, in relation to the critical conditions to be evaluated.
 - 2.1.6. Sample locations to be monitored.
 - 2.1.7. Parameters to be monitored at each sampling location.
 - 2.1.8. Frequency of monitoring for each parameter.
 - 2.1.9. Description of analytical equipment and methods to be used for monitoring each parameter.
 - 2.1.10 Quality assurance / quality control procedures to be used.
 - 2.1.11 Description of analyses to be used for evaluating the data collected.

2.2. A demonstration study should be conducted to simulate the breakthrough behavior of the GAC contactors for two empty bed contact times during the time of critical concern, i.e. time period of greatest DBP formation.

2.3. An appropriate amount of data should be collected to make a reasonable decision concerning GAC installation. The frequency at which the data is collected depends on whether the demonstration study is conducted at the bench, pilot or full scale. The following data should be collected for the demonstration study:

2.3.1. TOC

Raw Water
GAC Influent
GAC Effluent

2.3.2. Dissolved Organic Carbon (DOC)

Raw Water
GAC Influent
GAC Effluent

2.3.3. Specific UV absorbance (SUVA)

The SUVA is the ratio between UV absorption and the DOC in a water sample. SUVA can be used as a surrogate measurement to characterize the aromatic nature of the dissolved organic carbon. For certain drinking-water treatment plants that cannot meet the overall Total Organic Carbon removal requirements, they may still be considered in compliance if the SUVA is equal to or less than 2.0 liters per milligram-meter.

Raw Water
GAC Influent
GAC Effluent

2.3.4. Total Alkalinity

Raw Water

2.3.5. Simulated Distribution System (SDS) Total THM (It is recommended data corresponding to the average residence time of the distribution system be collected using Standard Method 5710 C).

GAC Influent
GAC Effluent

2.3.5.1. pH

2.3.5.1.1. Since pH is a factor that affects the amount of DBP formed, the pH of the treated GAC effluent should be that of the actual SDS water sample (± 0.2).

2.3.5.2. Temperature

2.3.5.2.1. Since water temperature is a factors that affects the amount of DBP formed, the SDS water temperature should be comparable to the actual distribution system temperature. The goal should be a simulated water temperature within ± 2 °C of the water entering the distribution system. If major temperature fluctuations occur in the distribution system, the actual DBP monitoring location should be the basis for the temperature goal.

2.3.6. SDS HAA5 (Standard Method 5710 C)

GAC Influent
GAC Effluent

2.3.6.1. pH

2.3.6.1.1. Since pH is a factor that affects the amount of DBP formed, the pH of the treated GAC effluent should be that of the actual SDS water sample (± 0.2).

2.3.6.2. Temperature

2.3.6.2.1. Since water temperature is a factors that affects the amount of DBP formed, the SDS water temperature should be comparable to the actual distribution system temperature. The goal should be a simulated water temperature within ± 2 °C of the water entering the distribution system. If major temperature fluctuations occur in the distribution system, the actual DBP monitoring location should be the basis for the temperature goal.

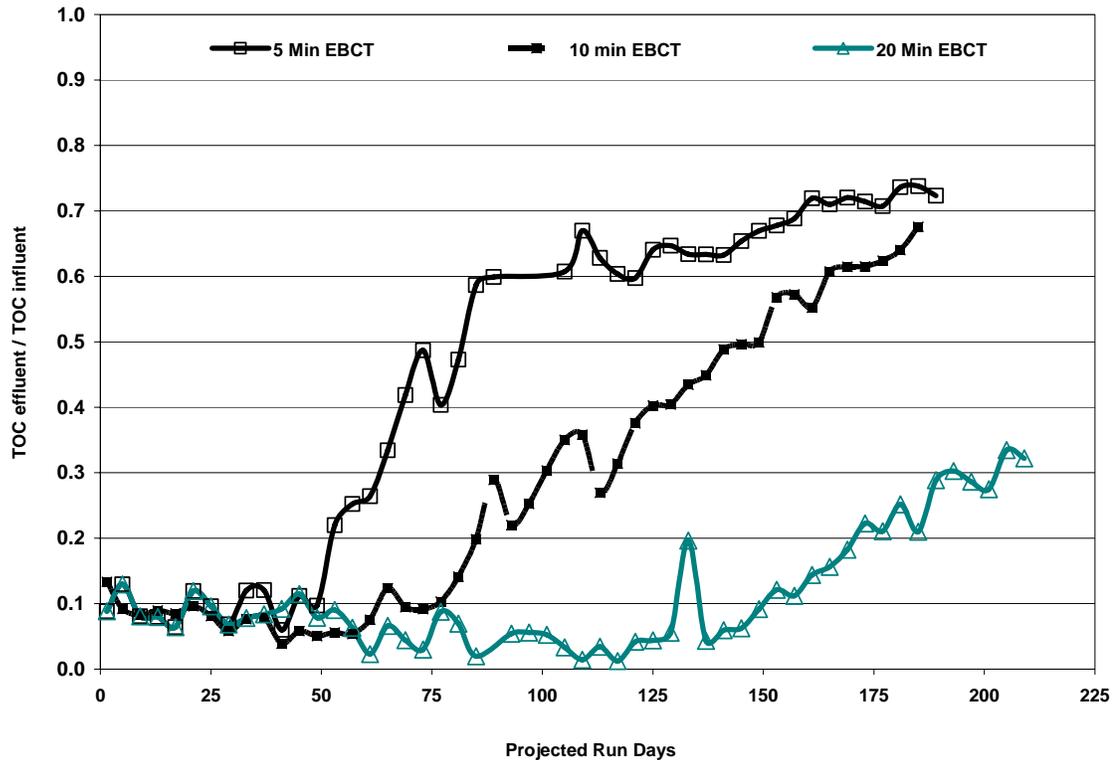
2.3.7. Other Data

Iodine number of the GAC prior to and at the end of study for comparison
Effective size of GAC media
Empty Bed Contact Time
Target pH and disinfectant dose for SDS data
Initial pH and disinfectant dose for SDS data
Final pH and disinfectant dose for SDS data
Simulated and actual distribution system water temperature

2.4. Data analysis should consist of at least:

2.4.1. TOC

2.4.1.1. A TOC breakthrough curve plotting the normalized concentration of TOC effluent for each EBCT. The normalized TOC concentration is the effluent TOC divided by the influent TOC concentration.



2.4.1.2. Ohio EPA requirements for TOC Removal

The requirements for TOC removal shown in the following table are in rule 3745-81-77(F)(2) of the Ohio Administrative Code:

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as CaCO ₃)		
	0-60	>60 - 120	>120
> 2.0 - 4.0	35%	25%	15%
> 4.0 - 8.0	45%	35%	25%
> 8.0	50%	40%	30%

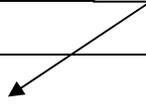
2.4.2. Specific Ultraviolet Absorbance (SUVA)

2.4.2.1. SUVA is equal to the UV absorption at 254nm (UV₂₅₄) (measured in m⁻¹) divided by the DOC concentration (measured as mg/L). In order to determine SUVA, it is necessary to separately measure UV₂₅₄ and DOC. DOC and UV₂₅₄ samples used to determine a SUVA value must be taken at the same time and at the same location.

2.4.3. Total Trihalomethane (TTHM)

2.4.3.1. Compare actual compliance system DBP data with corresponding SDS data.

Example of comparison:

		Actual Compliance Data	Actual and/or demo Data
Quarter	Demonstration study data	µg/L	µg/L
1		60	60
2		59	59
3		145	45
4		77	77
RAA		85.25	60.25

Note: Compliance is based on the Running Annual Average (RAA) under stage 1 of D/DBP Rule, and on the locational running annual average (LRAA) under stage 2.

2.4.4. HAA5

2.4.4.1. Compare actual compliance system DBP data with corresponding SDS data.

3.0 Review Criteria

The review criteria will be used by Ohio EPA to provide comments to the owner.

3.1. A report should be submitted in which the data collected, results of the data analysis, and the conclusions and recommendations are presented and clearly summarized. All data should be submitted in electronic format.

3.2. TOC

3.2.1. The calculated TOC value (ratio of actual/required) as determined as per Ohio EPA TOC MOR 5115 report instructions should be > 1.0.

3.3. SUVA

3.3.1. SUVA values obtained on the GAC effluent should at least be less than 2.0 L/mg-m.

3.4. TTHM

3.4.1. The estimated RAA TTHM value calculated using the demonstration study TTHM value during critical time period should be < 80 µg/L.

3.5. HAA5

- 3.5.1. The estimated RAA HAA5 value calculated using the demonstration study HAA5 value during critical time period should be $< 60 \mu\text{g/L}$.

V. HISTORY

The Division of Drinking and Ground Waters first issued this policy on September 17, 2007.

Appendix: Example of small PWS approach to compliance with D/DBPR rules

Overall Approach

This small system public water system's (PWS's) overall approach for selecting an appropriate and cost-effective means to comply with Stages 1 and 2 of the D/DBPR was to:

- Conduct a workshop with a consulting engineering firm to preliminarily examine the available alternatives,
- Perform a desk-top evaluation of the available alternatives to identify the feasible alternatives,
- Generate bench-scale data for the feasible alternatives,
- Evaluate the bench-scale data and compare feasible alternatives to determine the most-feasible alternatives,
- Develop planning-level cost estimates of the most-feasible alternatives, and
- Select the most appropriate and cost-effective alternative for implementation.

Potential Alternatives

The potential alternatives initially considered for selecting and implementing operational changes/capital improvements at the existing 1.0-MGD WTP can be grouped in three categories:

1. Chemical optimization,
2. GAC adsorption, and
3. Alternate disinfectants.

The Chemical Optimization Alternatives included:

- Enhanced coagulation,
- Enhanced softening,
- Enhanced coagulation/softening, with different levels of pre-oxidant addition,
- Enhanced coagulation/softening, with and without powdered activated carbon (PAC) addition, and
- Enhanced coagulation, with and without acid addition to conduct enhanced coagulation at lower pH values.

The GAC Adsorption Alternatives included:

- GAC as a filter cap in place of anthracite in the dual-media filters, and
- GAC as a post-filter, adsorption unit.

The Alternate Disinfectant Alternatives included:

- Chloramines, and
- Chlorine dioxide.

In addition to compliance with Stages 1 and 2 of the D/DBPR and the LT1ESWTR, the City wanted to make sure the selected alternative was compatible with other alternatives that might be necessary for compliance with the future requirements of the LT2ESWTR. Therefore, it considered the compatibility of the selected alternative with potential future alternatives, such as:

- Ultraviolet (UV) radiation, and
- Intermediate-ozonation followed by biologically-active filtration (BAF).

The possible need for these two alternate modes of disinfection would depend on the densities of *Cryptosporidium* measured in the future in the City's source water. UV could be incorporated into the WTP in the future if necessary. Intermediate ozonation followed by BAF would be more difficult to retrofit into the existing WTP. Ozone/BAF could potentially help solve the City's current DBP issue and inactivate *Cryptosporidium* in the future. However, it is not likely that ozone/BAF would remove sufficient quantities of the TOC, and it is uncertain if the City would ever need to inactivate *Cryptosporidium*. Also, data for properly evaluating the effects of ozone/BAF could not be gathered at the bench scale, and a more expensive and time consuming pilot-scale study would have to be conducted. Therefore, UV and ozone/BAF were not evaluated as part of this project.

Bench-Scale Evaluation

Several series of bench-scale jar tests were conducted to evaluate:

- Enhanced Coagulation,
- Enhanced Softening,
- Two-Stage Enhanced Coagulation/Softening,
- Single-Stage Enhanced Coagulation/Softening,
- PAC Addition, and
- Pre-Oxidation with potassium permanganate and chlorine dioxide.

Additional bench-scale testing was performed to compare DBP formation for alternate disinfection strategies (i.e., chlorine, chloramines and chlorine dioxide).

Rapid, small-scale column tests (RSSCTs) were also conducted at the bench scale to evaluate GAC adsorption at empty-bed contact times (EBCTs) of 7.5 and 20 minutes. These two times correspond, respectively, to those associated with using GAC as a filter cap in place of the anthracite in the existing filters, or as post-filter adsorption units.

Results of the Bench-Scale Evaluation

Evaluation of results of the bench-scale studies revealed:

- *Enhanced coagulation is most likely not necessary for TOC-removal compliance.* The City would not have to practice enhanced coagulation as a result of either the source-water or finished-water SUVA value being less than 2.0 L/mg-m.

- *Enhanced TOC removals can be achieved by increasing the coagulant dose, or the softening pH value.* Results of jar tests indicated that approximately 18 mg/L of ferric chloride would remove 35 percent of the TOC. Increasing the pH value during softening to approximately 10.6 resulted in enhanced TOC removal attributed to co-precipitation with magnesium hydroxide.
- *Single-stage and two-stage treatment yield similar results.* Similar removals of TOC were observed for various combinations of enhanced coagulation and softening applied in both single-stage and two-stage modes of operation. The maximum measured difference in TOC removal was only 0.2 mg/L. Therefore, operating the WTP's upflow clarifiers in series provides little benefit.
- *PAC addition is ineffective.* Utilizing the current points of chemical addition, adding PAC, potassium permanganate, ferric chloride and sodium hydroxide in the rapid-mix units would not dramatically improve TOC removal. With a dose of 30 mg/L PAC, TOC reduction increased by only 0.2 mg/L.
- *Pre-oxidation only impacted settled-water turbidity.* The removal of organics was not impacted by pre-oxidation. Of all the water-quality parameters measured, only the disinfectant residual and turbidity of the settled water appeared to be impacted by either the dose or type of pre-oxidant applied (KMnO₄ or ClO₂).
- *Alternate disinfection strategies could be considered (see Figures 2 and 3).* Switching to chloramines in the distribution system, or completely replacing free chlorine with chlorine dioxide, appear to provide the necessary level of TTHM formation control.
- *GAC removed the TOC (see Figures 4 and 5).* Data revealed that the removal of organic material and the subsequent formation of TTHMs and HAA5 for EBCTs of 7.5 and 20 minutes were equal on a bed volume of water-treated basis.
- *GAC as a filter cap would have limited life.* If the anthracite in the filters was replaced with GAC, it would be expected to provide an adequate barrier to the excessive formation of TTHMs for only about 2 months. Longer life would be anticipated with longer contact times, or if additional TOC was removed prior to the GAC-adsorption process.

Based on findings from the bench-scale study, two strategies emerged as the most feasible for long-term control of DBPs and consistent compliance with Stages 1 and 2 of the D/DBPR:

1. Addition of GAC adsorption, or
2. Switching to chlorine/chloramines or chlorine dioxide.

GAC adsorption offers a significant advantage over chloramination or chlorine dioxide. GAC removes the organic compounds that cause the formation of DBPs in the distribution system (in addition to the removal of taste-and-odor causing substances). Chloramines and chlorine dioxide do not remove the organics, but do not form the regulated DBPs that are formed when chlorine is used for disinfection.

Selected Alternative

There are two means of implementing GAC adsorption at the existing WTP:

1. Using GAC as a filter cap by replacing the anthracite media in the existing dual-media filters, or
2. Providing separate post-filter, GAC adsorption units.

The existing, dual-media filters at the WTP have a total media depth of 30 inches. Ohio EPA requires a minimum sand-layer depth of 12 inches. Therefore, the deepest GAC-media depth that could be installed (i.e., replacing the existing anthracite media) is 18 inches. This would result in an EBCT of 15 minutes at a water-production rate of 0.5 MGD, and an EBCT of 7.5 minutes at a production rate of 1 MGD. GAC adsorption as a filter cap replacement can be easily implemented, but it has distinct disadvantages:

- a short EBCT – i.e., more frequent regeneration,
- the GAC would be used year round since it would be part of the filters – i.e., continually exposing the GAC to organics and leading to more frequent regeneration,
- more frequent regeneration/replacement of the GAC,
- inability to easily remove the GAC cap for regeneration/replacement (i.e., due to intermixing of the GAC and sand media), and
- more likely to violate filter-effluent turbidity requirements of the enhanced SWTRs since the GAC has to be frequently removed for regeneration.

The Selected Alternative was to provide two, post-filter GAC units with a diameter of 12 ft and a media height of 10 ft. This provides a total of 2,260 cf of GAC media. The RSCCTs revealed that a treated-water volume equal to 15,000 bed volumes would ensure compliance with the DBP requirements for both Stage 1 and Stage 2 of the D/DBPR. The two 12-ft diameter columns would be sufficient for the treatment of approximately 250 MG of water. This far exceeds the average annual water production at this PWS. The GAC media would have to be either regenerated or replaced on an annual, or even less frequent basis.

The preliminary, planning-level capital cost estimate is \$650,000 for the installation of two, 12-ft diameter post-filter, adsorption columns. The annual operation and maintenance (O&M) cost for media replacement is estimated to be approximately \$70,000 (based on a cost of approximately \$1/lb of GAC). A lower annual O&M cost is expected if the GAC media are regenerated instead of being replaced.

Achieving compliance with **chloramination** in the PWS's distribution system would require the installation of an ammonia storage-and-feed system. To continue satisfying the CT requirements of the SWTR, additional capital improvements would also be required:

- Compartmentalize the existing circular clearwell and add ammonia to the effluent from the first compartment. This would provide a free chlorine contact time of

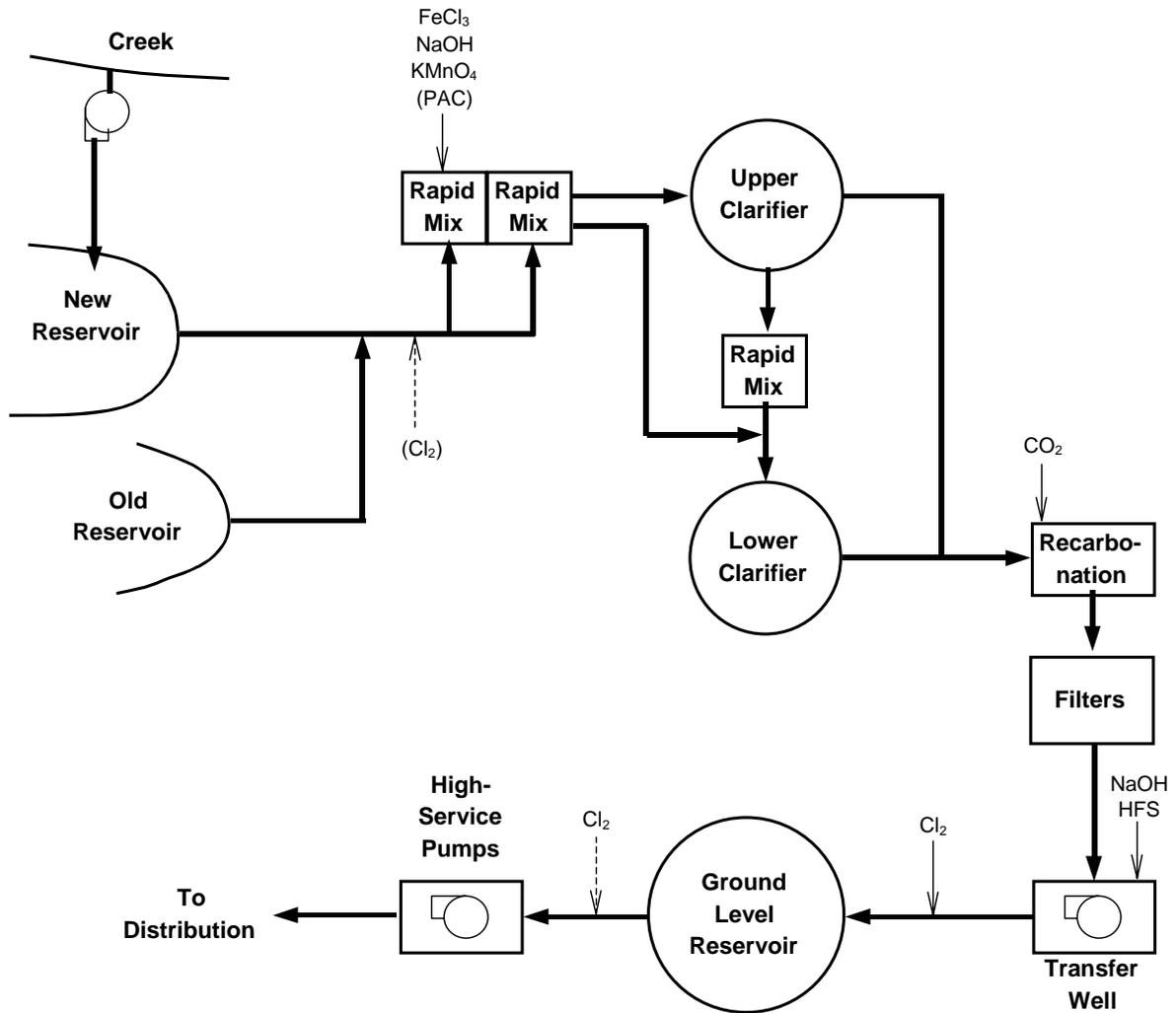
approximately one hour in the first compartment to satisfy the CT requirements;
or

- Construct a smaller clearwell (40,000 to 50,000 gallons) upstream of the existing clearwell (to satisfy the CT requirements with free chlorine) and add ammonia to the effluent from this new clearwell. Construction of a new, smaller clearwell would be difficult to implement because of the location of the existing low-head transfer pumps, and additional pumping would likely be required.

Chloramination would also require more time to implement because a demonstration study would have to be conducted to obtain Ohio EPA approval of chloramination. Also, chloramination would require significantly more operator vigilance in operating the distribution system due to the need for additional monitoring and flushing.

Compliance could also be achieved with **chlorine dioxide**, with either chlorine dioxide as the primary and secondary disinfectant, or chlorine as a primary disinfectant and chlorine dioxide as the secondary disinfectant. The use of chlorine dioxide has a distinct limitation; the chlorite formed from the decay of chlorine dioxide. Chlorite is a DBP regulated by Stage 1 of the D/DBPR. The chlorite MCL is 1.0 mg/L. This level of chlorite can be formed with a chlorine dioxide dose of slightly above 1 mg/L. This would limit the use of chlorine dioxide at this PWS as an alternative disinfectant. Also, the calibration and monitoring requirements would increase for chlorine dioxide.

Figure 1. Flow Schematic of WTP



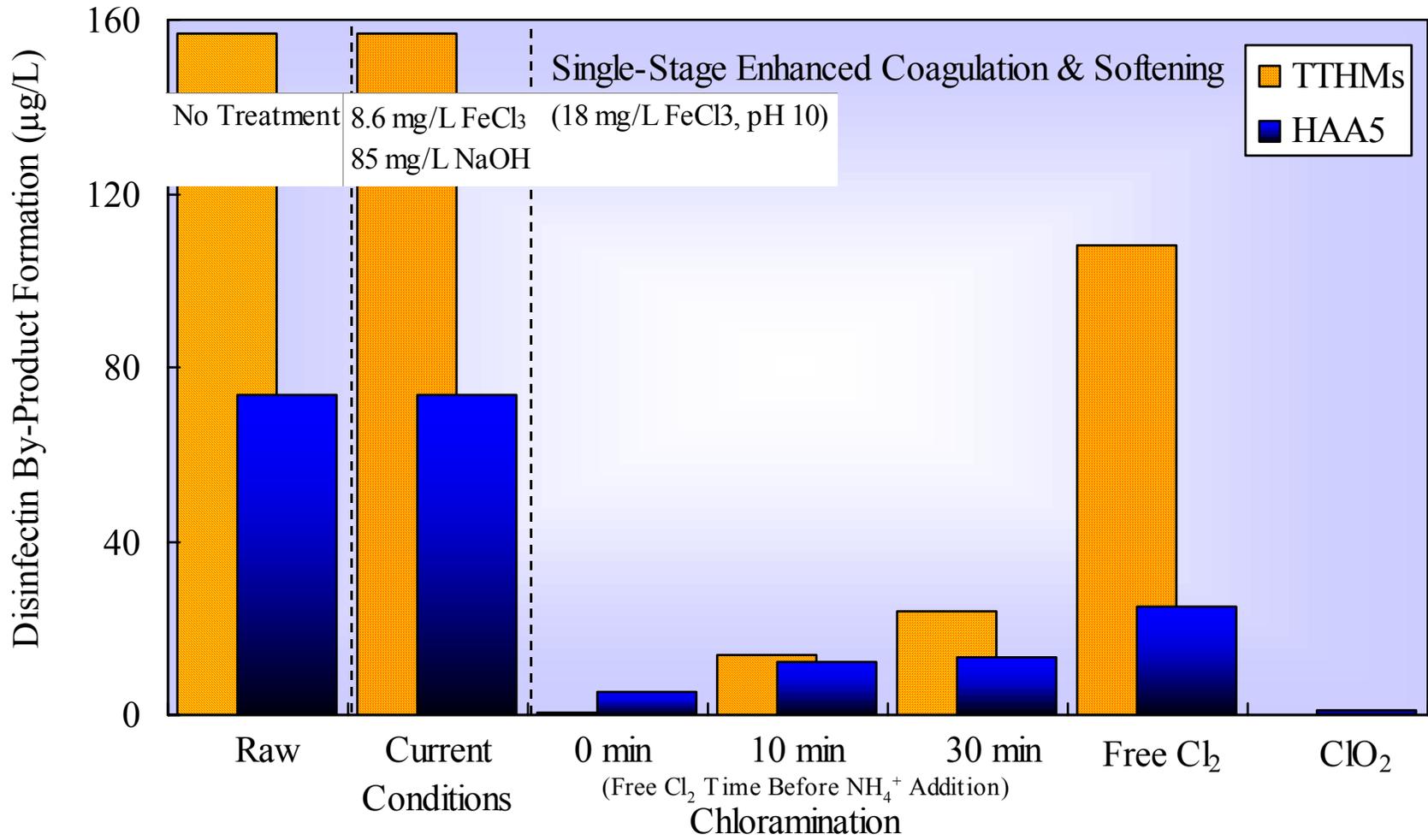


Figure 2. Use of Chloramines vs. Free Chlorine Contact Time

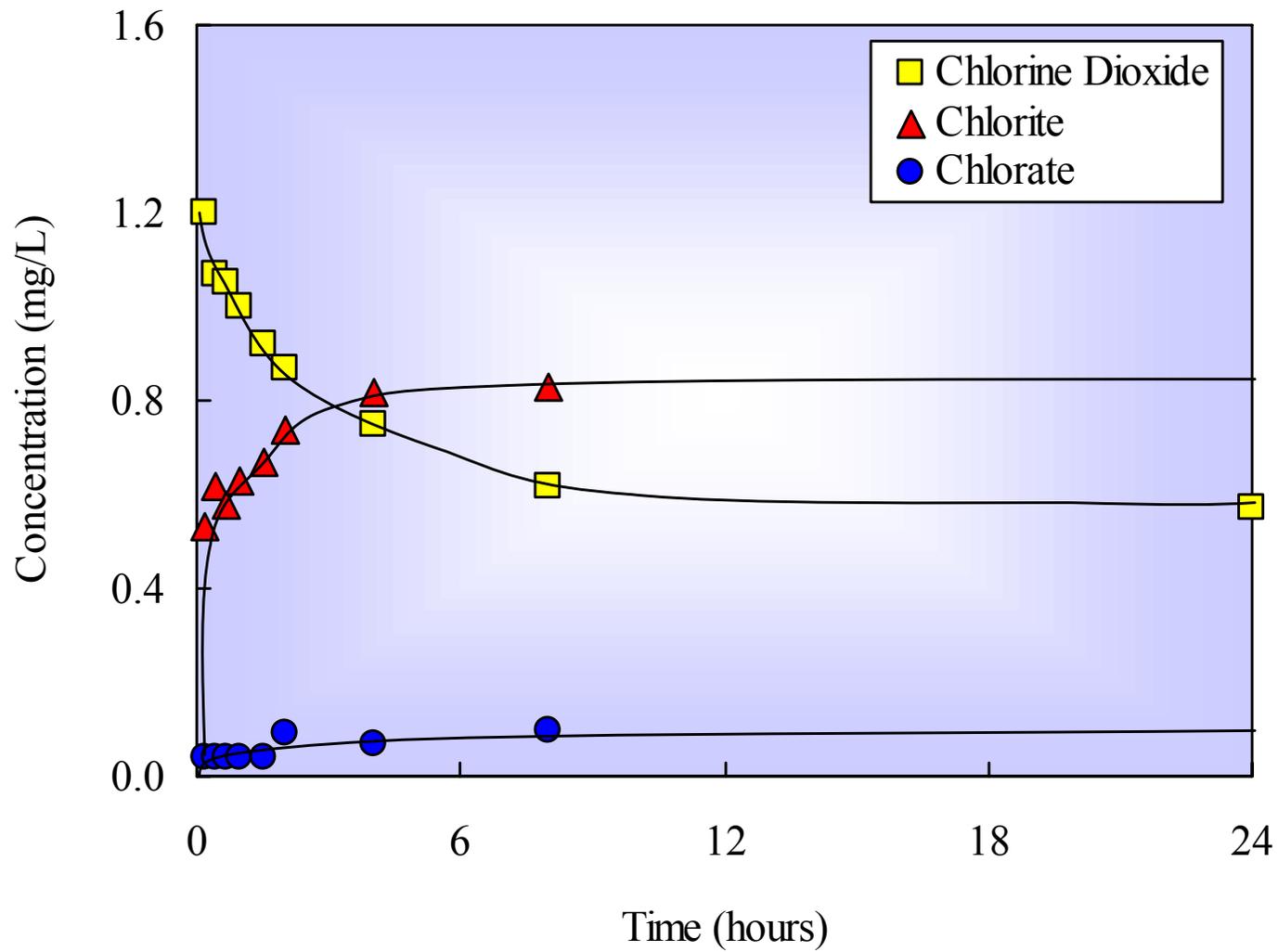


Figure 3. Chlorine Dioxide Residual and Chlorite Formation vs. Contact Time

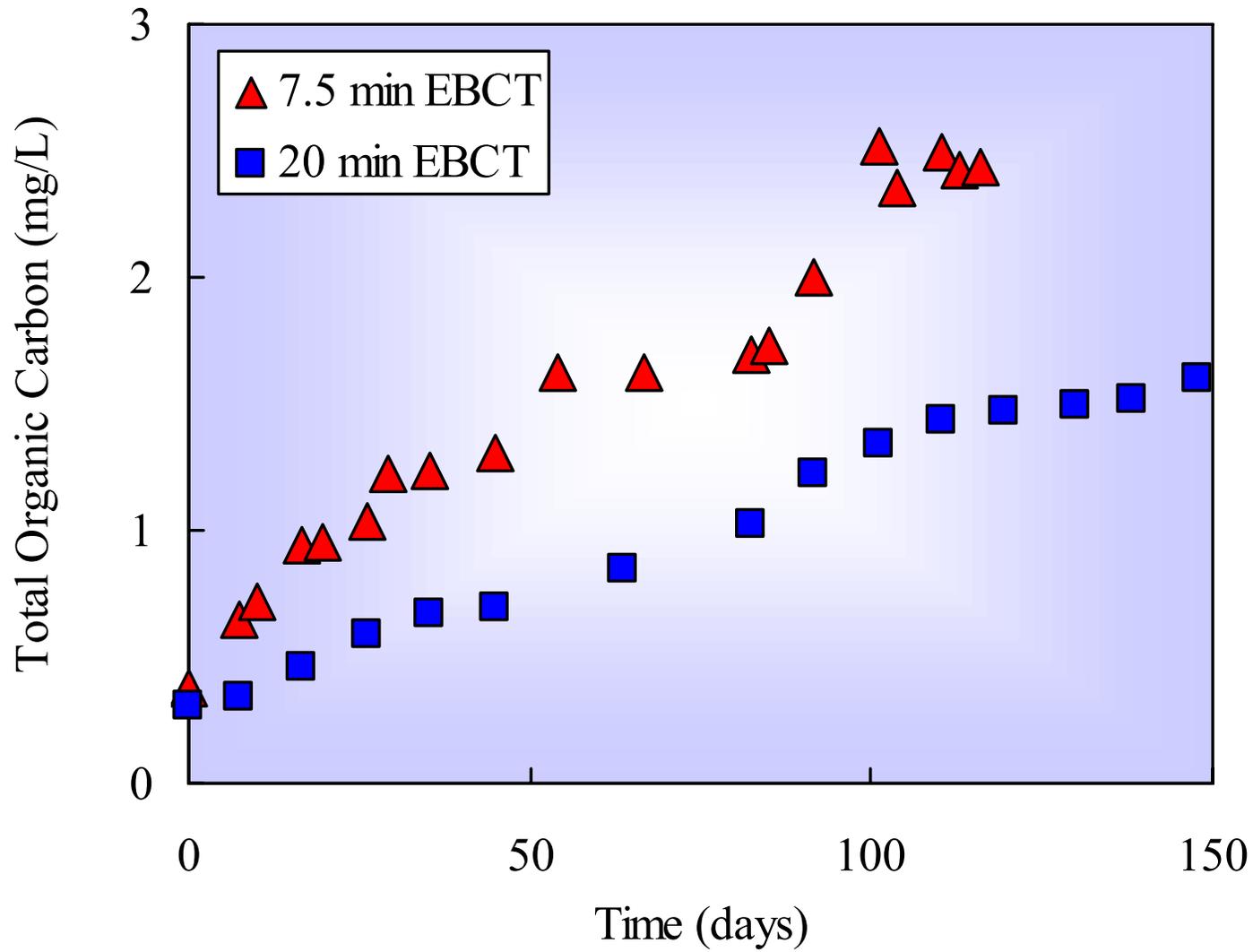


Figure 4. GAC Adsorption – Effluent TOC Concentration vs. Time

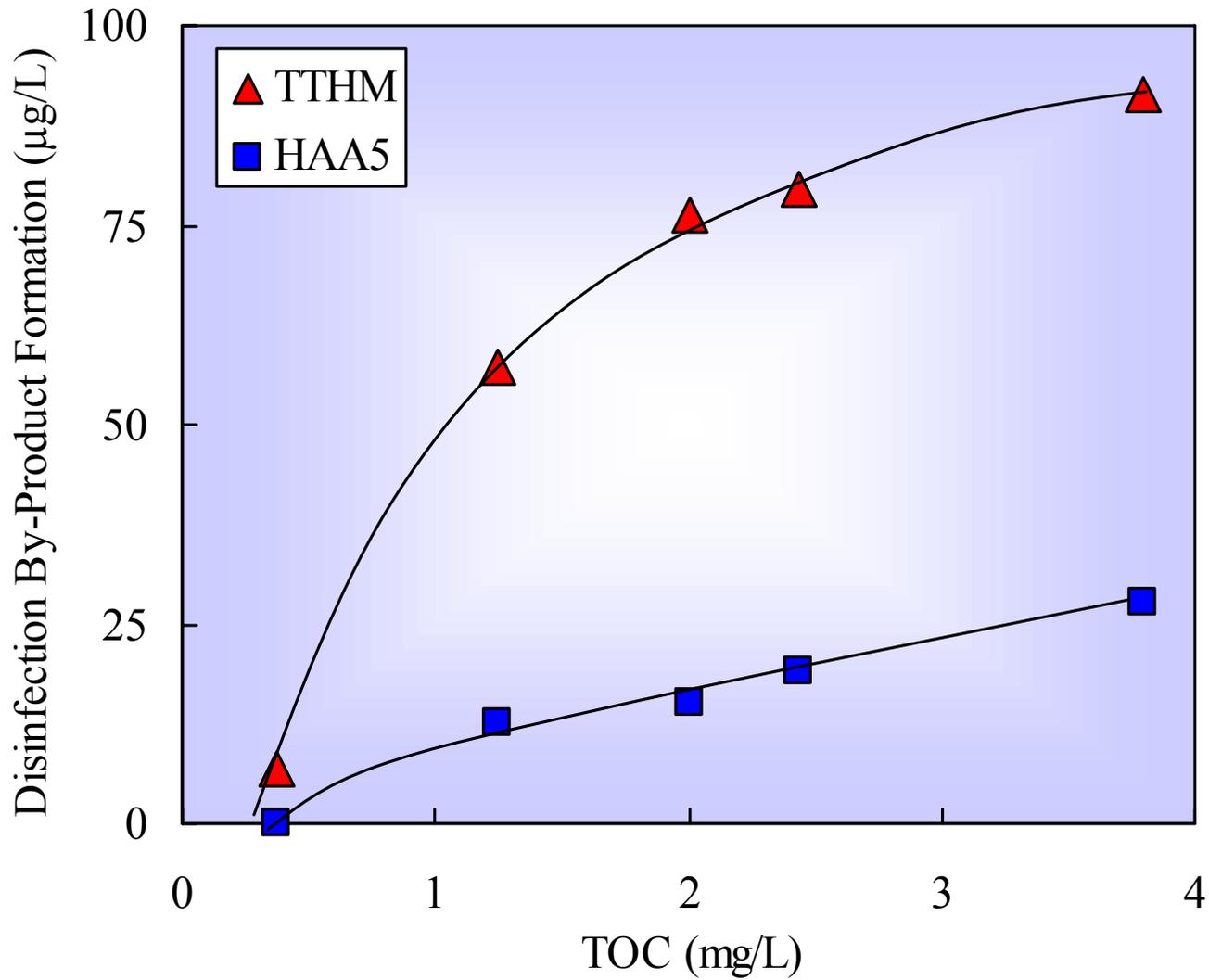


Figure 5. GAC Adsorption – DBP Formation vs. TOC Concentration in GAC Effluent