Localized Treatment for Reduction of Disinfection Byproducts

Chandra Mysore

Stage 2 of the Disinfectants and Disinfection Byproduct Rule (D/DBPR) requires total trihalomethanes (TTHMs) and haloacetic acids (HAAs) to be below 80 parts per bil (ppb) and 60 ppb at each monitoring location in the distribution system. As an alternative to treating the entire flow at a centralized facility, many utilities are considering treating only a partial flow in the distribution system to be in compliance with the Stage 2 D/DBPR requirements. Localized or decentralized treatment at the point of noncompliance is a cost-effective option, as only the flow that is necessary is treated to be in compliance with the Stage 2 regulations.

As an example of localized treatment, air strippers remove volatile organic compounds (VOCs) from liquid (water) by providing contact between the liquid and gas (air). The gas (air) may then be released to the atmosphere or treated to remove the VOCs, and subsequently released to the atmosphere. In general, the removal efficiency of air stripping for trihalomethanes (THMs) is as follows:

Chloroform>Bromodichloromethane>
Dibromochloromethane>Bromoform

This article presents an overview of DBP issues, options for localized treatment for the reduction of DBPs, and results from a case study.

Overview of Disinfection Byproduct Issues

The DBPs form during treatment at water treatment facilities and over time in the distribution system when chlorine reacts with the natural organic matter (NOM) quantified as total organic carbon (TOC) in the water. Amendments to the Safe Drinking Water Act in 1996 required the U.S. Environmental Protection Agency (EPA) to develop rules to balance the risks between microbial pathogens and DBPs. The Stage 1 D/DBPR and Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, were the first phase in a rulemaking strategy required by Congress as part of the 1996 amendments. In the Stage 1 rule, utilities were given a "not to exceed" goal of 80 µg/L for THMs in their distribution systems. In addition, utilities were given goals for enhanced coagulation to maximize the removal of TOC, which is a DBP precursor.

The Stage 2 D/DBPR builds upon the Stage 1 rule to address higher-risk public water systems for protection measures beyond those required for existing regulations. In the Stage 2 rule, the running annual average is based on a locational compliance level of 80 µg/L for THMs and 60 µg/L for HAAs. The Stage 2 rule is focused on reducing the risk of elevated DBPs at specific locations in the distribution system. Increased organic concentrations, water age, and/or temperatures can lead to increased DBP formation.

The THM formation is controlled by the following factors:

1. *Reactions of Chlorine with TOC* – Certain subsets of TOC react with oxidants, resulting in DBP formation. Removal of TOC before disinfection can reduce the formation of DBPs.
2. *Chlorine Dose (or Chlorine Demand)* – The addition of more chlorine leads to more DBP formation. The necessary chlorine dose is typically controlled by disinfection contact time requirements and maintaining a residual concentration throughout the distribution system.
3. *Water Age in the Distribution System* – Longer reaction times result in more DBP formation. Water age often can be controlled in a distribution system by implementing best practices, such as tank management and flushing programs.
4. *Water Temperature* – Higher temperatures result in faster DBP formation. Water temperature cannot be controlled by treatment operations.
5. *Finished Water pH* – Higher pH can result in the formation of more THMs. The finished water pH is typically set for operational reasons, such as corrosion control.

There are three basic methods of reducing DBPs in distribution systems:

1. Remove and/or change the form of DBP precursors, such as TOC.
2. Reduce DBP formation in the distribution system by adding ammonia to form chloramines and essentially quenching the formation of THMs, or reduce the water age within the distribution system.
3. Remove formed DBPs through the use of physiochemical processes, such as adsorption, aeration, or membranes.

Chandra Mysore, Ph.D., P.E., BCEE, is technology director with Jacobs in Atlanta.

Disinfection Byproduct Removal Methods

This section focuses on the removal of THMs after they have been formed. The following treatment technologies can be evaluated for their ability to remove TTHMs in the distribution system:

- *Aeration* – Volatilizing the THM compounds though air dispersion. Several forms of aeration are available: spray aeration, air stripping, or diffused aeration.
- *Granular Activated Carbon (GAC)* – THMs are adsorbed onto carbon media.
- *Membrane* – THMs are removed in the gas phase though the membrane.

It should be noted that these THM removal methods could be implemented on a seasonal basis to capture the THM peaks.

Aeration

Diffused Aeration

In diffused aeration, air is blown into a network of diffusers installed at the bottom of a tank of water. The diffusers release the air in bubbles that collect volatile compounds, including THMs, as the bubbles rise to the surface of the water. A recent study predicted various THM removals using a 20:1 to 65:1 air-to-water ratio (AWWARF, 2009). The removal rates varied widely, depending on the THMs. Notably, chloroform, which is one of principal THMs of concern, has the highest and most efficient removal rates: 95 percent for 20:1 air-to-water ratio.

Spray Nozzle Recirculation System

The system consists of a submersible pump that would recirculate water in the tank through spray nozzles placed on the tank's ceiling. Water would be aerated when passing through the

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spray nozzles, and THMs would thus be stripped from the water. Ventilation outlets and air extractors are installed in the roof of the tank to continually remove THMs from the air in the headspace of the tank. Capital cost items for the spray nozzle recirculation system include submersible pumps, ventilation system, stainless steel piping, and electrical upgrades. A recent study predicted 75 to 80 percent TTHM removal using a 10:000:1 air-to-water ratio for spray aeration (AWWARF, 2009). The spray aeration system includes the following components:

- Spray aerator
- Piping
- Submersible pump
- Tank roof ventilation

SolarBee

The SolarBee THM removal system is a patented, proprietary system that incorporates solar-powered mixing and grid-powered diffused aeration using a blower to achieve DBP reduction (Figure 1). The expected THM removal efficiency is 50 percent.

Any of the aeration systems mentioned would require blowers to be placed at the storage tank location. Proper sound protection would need to be provided to minimize sound impact to the local residences, if they are close to the tanks.

Air Stripping

In packed tower air stripping or an air stripper, water is pumped to the top of a bed of packing media, where it flows by gravity in contact with a flow of air that is blown into the tower below the packing media. The treated water flows by gravity out of the bottom of the tower, and the air containing the THMs exits from the top of the tower.

Based on previous studies (AWWARF, 2009), air strippers are expected to provide an

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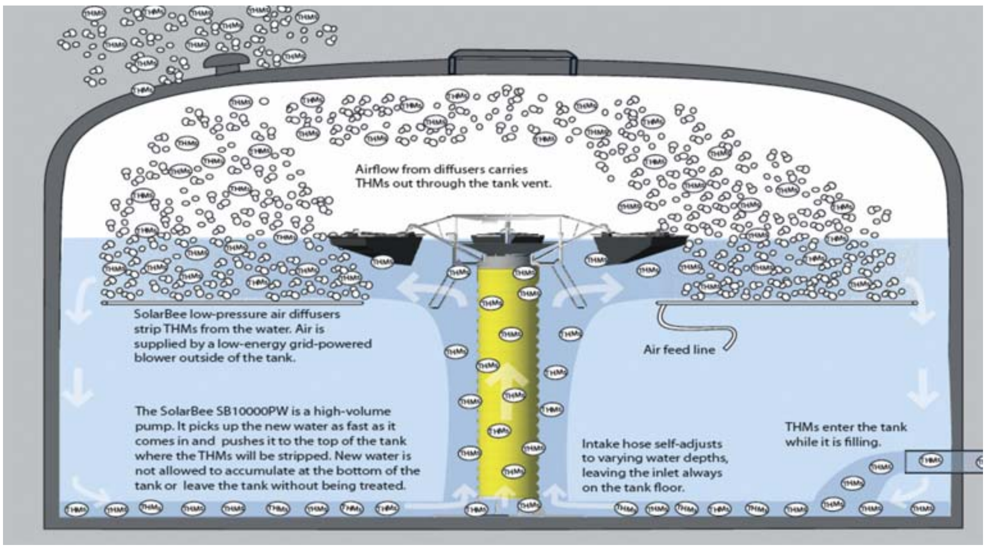
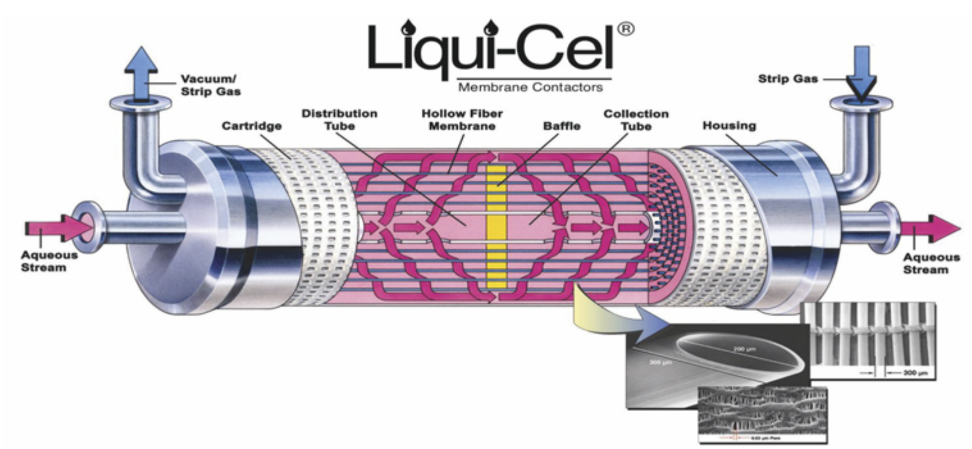


Figure 1. SolarBee Process Schematic

Figure 2. Low-Profile Air Stripper



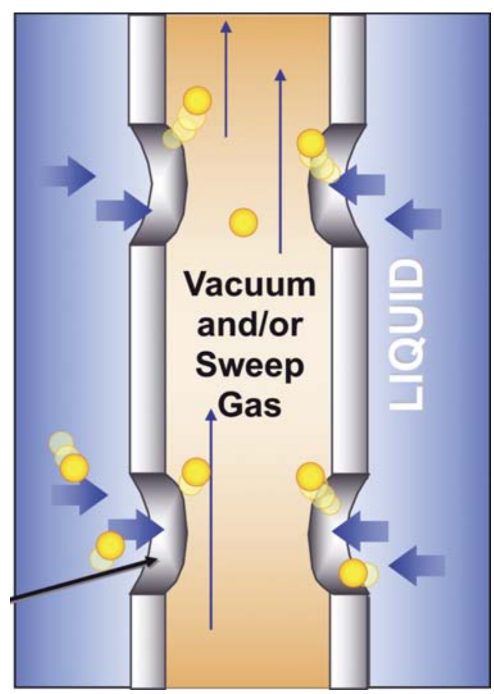


Figure 3. Membrane Contactor and Membrane Air Flow

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average THM removal of 75 to 85 percent. Air strippers are not effective at removing HAAs or TOC, but can remove some chlorine. Air strippers are typically stand-alone units that can be installed in a relatively small area and require little maintenance. Careful consideration must be given to distribution system hydraulics, if air stripper towers are used, because the air stripper effectively removes the head from the system at the point where it's installed, which is a significant drawback. Figure 2 provides an example of a low-profile stripper that could be used in lieu of a traditional packed tower aerator.

Granular Activated Carbon

The GAC removes THMs and HAAs through adsorption onto the carbon media and has the advantage of removing both the THMs and the organic material in the water that reacts with chlorine to create THMs. The GAC also removes the chorine residual and could be operated as a seasonal solution to the THM issue. The usual operation is 10 minutes of empty bed contact time based on the flow rate; typically, 10,000-bed volumes are achieved before breakthrough. Research has shown that more than 80 percent of THMs were removed by GAC through a media life of 10,000-bed volumes at a 10-minute empty bed contact time (i.e., 22 liters of water treated per gram of GAC). If GAC is selected for implementation, rapid small-scale column tests on the distribution system water should be conducted to determine the actual carbon usage rates for the system.

Membranes

Membranes have recently been piloted for removal of THMs and are specifically designed to separate the gas from the liquid phase; the membrane permits the flow of air/gases through the media, while preventing water from passing through. Figure 3 presents a depiction of the liquid and air flow through the membrane module and an overall process schematic.

Layne Christensen (Layne), which packages the membrane equipment, has conducted several pilot programs with membranes for THM removal (the membranes are manufactured by Membrana). Layne reported 70 to 85 percent THM removal through a single membrane, and levels increase to more than 90 percent when two units are operating in series. Figure 4 shows a recent installation for deaeration.

Membranes would be placed in line with the pump station discharge, thereby eliminating the need to repump. The membranes are adversely affected by the chlorine residual, so the rechlorination point would have to be moved downstream of the membrane system to increase the membrane life. Layne reports that the membranes can take 24,000 contact volumes before needing to be replaced.

Advantages and Disadvantages

This section presents the advantages and disadvantages of each option for localized treatment in the distribution system (in-tank solutions).

The objective of the project (as shown in the case study) was to identify the most reliable and cost-effective treatment to meet the requirements of the Stage 2 rule through decentralized treatment. The investigation included bench and pilot testing to determine performance of air stripping combined with GACs and developing models to determine TTHM and HAA formation.

Case Study

Desert Mountain is a golf course community in north Scottsdale. The biggest issue facing the community and the city is increased formation of THMs due to water age. The Central Arizona Project (CAP) Water Treatment Plant treats CAP water by coagulation, flocculation, sedimentation, and filtration. A portion or the entire allotment of this treated water flows to GAC beds for additional removal of organic matter. The water is then chlorinated and sent to the distribution system. It takes approximately three days, along with three chlorine-boosting stations, for the water to reach Desert Mountain, and then an additional seven days to reach its customers. In the summer, depending on water demand, CAP water may be blended using well water. The RES-92B site feeds the Desert Mountain water distribution system and is the last chlorine injection location. The THM levels during summer months can reach as high as 132 ppb. With three Stage 2 rule sites located within the Desert Mountain service area, a THM mitigation strategy was clearly needed.

Pilot-scale studies were conducted with two air strippers for THM mitigation at RES-92B. A horizontal (box) unit from Carbonair and a vertical (tower) unit from Bay Products/Enduro were evaluated for THM removal efficiency under various air-to-water ratios and blending scenarios. The study also examined the effect of aeration on chlorine residuals and addressed the

Figure 4. Full-Scale Application for Deaeration

Table 1. Summary of the Advantages and Disadvantages of In-Tank Options

TABLE 1: IN-TANK SOLUTIONS

Diffused Aeration		Spray Aeration		SolarBee	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Effective at stripping THMs	Aerators are submerged, requiring shutdown for maintenance	Lowest capital cost	Only treats a portion of the flow	Uses solar power for tank mixing	Only treats a portion of the flow
Low costs	Requires air permit	Small footprint	Requires air permit	Highest in-tank solution cost	Requires air permit
No new facilities	Potential public opposition	Rapid implementation	Potential public opposition		Potential public opposition
	Potential for DBP reformation after addition of chlorine		Potential for DBP reformation		Potential for DBP reformation

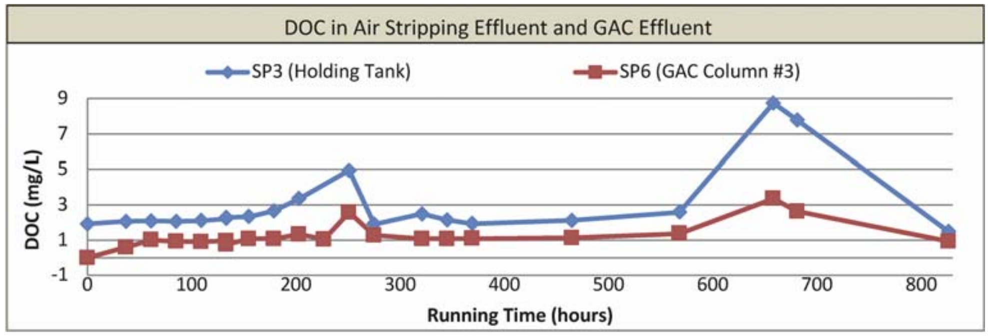

Figure 4. Dissolved Organic Carbon in Air Stripping Effluent and Granular Activated Carbon Effluent

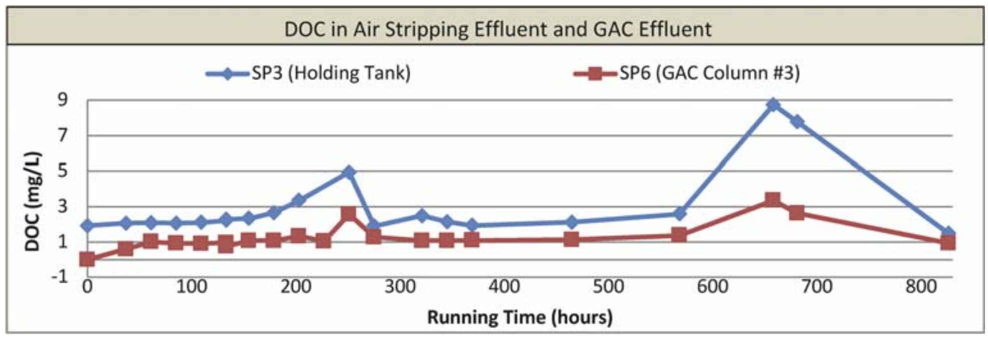

Figure 5. Air Stripping and Granular Activated Carbon Treatment Over Time

issue of THM reformation after air stripping. The results of this pilot study are presented elsewhere (Mysore et al., 2013).

The air stripping study at RES-92B concluded that air stripping is very effective in THM removal. It had minimal effect on chlorine residuals after air stripping, and THMs were reforming in the range of 50-80 ppb within 72 hours, depending on temperature and the water blending ratio (treated-untreated); however, due to the reformation of THMs, chlorine-boosting after the air stripping was needed to maintain the chlorine residual in the distribution system. It was also recommended that in the hot summer months, additional THM controls must be employed to make sure the city complies with Stage 2 D/DBPR regulations.

The objective of the pilot study was to use information gathered during previous THM reduction studies to determine an effective treatment strategy using air stripping and GAC to prevent the reformation of THMs in drinking water. The pilot test system consists of an air stripping unit connected in series to the GAC column apparatus installed at RES-92B, which is located at the entrance to Desert Mountain. The air stripping unit was a packed-column stripper from Bay Products/Enduro connected in series to the GAC column apparatus from Batelle, which consists of three 2-in. by 48-in. glass columns connected in parallel configuration for simultaneous testing of multiple columns (Mysore et al., 2013).

Influent water quality from the distribution system was used as a baseline for study comparison. There were no RES-92B influent samples collected after 37 hours because the incoming quality was expected to be relatively consistent following continuous GAC treatment at the CAP plant. Nearly 97 percent of the water received at RES-92B during the study was treated at the CAP plant, and the remaining quantity was pumped from distribution wells.

Dissolved organic carbon (DOC), the constituents of which are precursors to TTHM formation, ultraviolet $(UV)_{254}$, chlorine, temperature, and pH, were analyzed and recorded during Phase I. At system start-up, and 37 hours into the test, DOC results were 1.80 part per mil (ppm) and 1.89 ppm, respectively. Throughout the pilot study, the incoming DOC averaged 2.22 ppm, excluding the spikes occurring at 251 and 660 hours. As seen in Figure 4, after GAC treatment, DOC averaged 0.97, excluding the same spikes. Except in the beginning, DOC breakthrough was consistent throughout the study, with a value of approximately 46 percent. The bituminous GAC was effective at removing DOC, thereby reducing THMs.

Figure 5 shows that water quality improved as a result of air stripping, which effectively reduced THMs from RES-92B by 85 percent at 0 hours and 83 percent at 37 hours into the study. Although this is a significant reduction, THMs quickly reformed following air stripping, as seen in the previous pilot study (Mysore et al., 2013). Because of the unfortunate lack of RES-92B influent THM data throughout this study, it cannot be determined exactly how well THMs were removed by air stripping alone, as conditions changed (temperature, flow, and CAP plant treatment).

Figure 5 illustrates that, while SP3 THMs were quite variable and most likely changing with site conditions, the GAC-treated effluent from SP6 followed a very steady trend. For the first 300 hours, SP6 THMs were nonexistent; at approximately 400 hours, THMs began appearing in the effluent and slowly trended up to a maximum of 5 ppb at 826 hours. It's clear that air stripping and GAC were very effective in reducing THMs, and GAC was further inhibiting TTHM reformation by dropping DOC levels.

Summary

Localized or decentralized treatment at the point of noncompliance is a cost-effective option as only the flow that is necessary is treated to be in compliance with the Stage 2 regulations. Both air stripping and GAC treatments are effective approaches for reduction of TTHMs in the distribution system, but the reformation of TTHMs was of concern while using air stripping. Air stripping, combined with GAC, was very effective at removing THMs throughout the duration of the pilot study; therefore, the chosen localized treatment system should be designed to achieve a lower-target treated water TTHM level that will provide a buffer of a magnitude sufficient to ensure that TTHM levels do not exceed the 80 ppb limit with reformation, or should be followed by another treatment, e.g., GAC.

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References

- "Localized Treatment for Disinfection Byproducts." Johnson, B.A., Lin, J.C.; American Water Works Association and Research Foundation, Denver, Colo. (2009).
- "Comparing Centralized and Decentralized Treatment for Reduction of DBPs." Mysore, C., Roberts, W., Fletcher, J.; ACE Conference, Denver, Colo. (2013).