

Removal of THMs from Drinking Water Using an Induced Draft Stripping Tower

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Abstract

The control of disinfection byproducts in drinking water has become increasingly important in recent years, especially the group that includes the trihalomethanes. Most of the control efforts have been directed toward preventing their formation, but this project focused on removing them after they are formed. Because trihalomethanes are extremely volatile, it was believed that air stripping would be a feasible method for reducing their concentration in treated drinking water. Therefore, this study investigated the cost-effectiveness of using an induced draft stripping tower to remove some of the trihalomethanes from the treated water.

The results showed that air stripping using an induced draft packed column is indeed a highly effective method for removing THMs from water. At air-to-water ratios of 60 or greater, the percent removal of total trihalomethanes generally exceeded 90%. Furthermore, the stripping operation had no discernable effect on the residual chlorine concentration in the treated water.

Chloroform was the easiest THM to remove while bromoform was the most difficult. Percentage removals ranged from 69% to 96% for chloroform and 32% to 87% for bromoform.

The air-stripping operation appears to be very cost-effective, with the *operating cost* calculated to range from 0.37 to 1.1 *cents* per thousand gallons of treated water for the best-case and worst-case scenarios, respectively. When the amortized capital costs are added in, the *total costs* range from 0.92 cents per thousand gallons to 4.6 cents per thousand gallons for the best and worst-case scenarios, respectively. A *realistic* total cost estimate will lie somewhere between the two extremes values, but it is probably closer to the 0.92 cents per thousand gallon best-case value than it is to the worst-case one.

Introduction

Chlorine has been used for disinfecting water for over one hundred years. Its effectiveness is based on its high reactivity with organic substances, but while many of the chemical reactions that occur produce results that are exactly as intended, others produce end products that may be harmful to humans. Total Trihalomethanes (TTHM's) are one such group of by-products.

Trihalomethanes (THMs) are formed when chlorine reacts with certain precursors to form chloroform and other chlorinated substances that are believed to cause cancer in humans. Therefore, the United States Environmental Protection Agency (USEPA) has established a TTHM limit of 80 µg/L (ppb) in drinking water¹. Water utilities have responded in different ways, from changing disinfectants to changing processes in an attempt to prevent THM's from being formed. This project investigated the feasibility of *removing* trihalomethanes after they are formed by taking advantage of their extremely high volatility and stripping them from the water phase into the air phase.

Literature Review

Background

Massive typhoid outbreaks in the late 1800's and early 1900's led to the introduction of chlorinated water in the United States in 1908².

Unfortunately, along with this great advancement, new drawbacks arose. In the 1970's, scientists discovered that chlorine by itself did not pose any cancer threat in lab animals, but in the water treatment process, it created several disinfection-by-products (DBPs) that are possible carcinogenic compounds. The DBPs of biggest concern are currently the organic hydrocarbons, or total trihalomethanes³.

In 1979, the United States Environmental Protection Agency (USEPA) implemented a maximum contaminant level (MCL) for TTHM's of 0.10 mg/L as an annual average. The Safe Drinking Water Act (SDWA) has been modified over the years to set rigorous national water standards. The last change made to the SDWA effective in January 01, 2002 for systems serving more than 10,000 persons and on January 01, 2004 for systems serving less than 10,000 persons, included a new MCL for TTHM concentration of 80 µg/L (ppb)¹.

The association of TTHM's with carcinogenicity in humans and animals has been proven in controlled studies conducted by Melnick, Dunnick, Sandler, Elwell, and Barrett⁴. Their studies led to the conclusion that there is "an association between consumption of chlorination by-products from chlorinated surface water and increased risk for rectal cancer".

TTHM Formation/Control

Several factors influence the concentration of TTHMs in water, including the type of disinfectant used, precursor concentration, contact time, disinfectant dose, bromide concentration and temperature of the water⁵. The factor that is considered to have the most influence is the amount of organic carbon present in the raw water. Therefore, surface waters will have a higher potential for TTHMs than ground water.

There are three main ways in which TTHMs have been dealt-with over time: (1) elimination of precursors or naturally occurring organics from the water, (2) use of alternative disinfectants, and (3) removal of the DBPs after their formation. Currently, the most accepted ways of preventing DBPs would be to either eliminate precursors by using enhanced coagulation in the treatment process, or to switch to an alternative disinfectant to reduce the formation of the harmful by-products.

Alternative Disinfectants

Alternative disinfectants for chlorine include chloramines, chlorine dioxide and ozone. The advantages and disadvantages for these alternative disinfectants go from reducing currently known DBPs to forming new and potentially more hazardous DBPs. Chloramines are a popular alternative disinfectant because they form a long-lasting residual and have low taste and odor problems in the distribution system. Chloramines are well known for their ability to lower TTHMs and other regulated DBPs. Faust and Aly⁶ proved that they lower TTHMs by 72% to 79% and research conducted by the American Water Works Association (AWWA) Research Foundation showed that the most common range in which chloramines reduced TTHMs was between 40 and 80 percent⁷.

On the other hand, Chloramines have proven that they could be unsafe to people with kidney problems as well as to fish in rivers and streams. Some of the DBPs found in water treated with chloramines include Iodoacid DBPs which are formed when water with a high bromide/iodide concentration is treated with chloramines. The Iodoacid DBPs are classified as highly toxic contaminants and mutagenic, although the toxicity to humans is not fully known as yet⁸.

Chlorine Dioxide and Ozone had a strong start after the Cryptosporidium outbreak in Milwaukee, when many utilities embarked on a new search for more advanced disinfectants⁹. Chlorine Dioxide studies have shown that it is efficient in reducing trihalomethanes when in combination with chlorine¹⁰ (Rittmann, 2002). One disadvantage of chlorine dioxide is safety issues related to its production, since it has to be produced on site¹¹.

Ozone, according to Faust and Aly⁶, is the second most popular disinfectant after chlorine. This is probably due to its strong oxidizing abilities, since it is a good disinfectant for bacteria as well as viruses. One disadvantage of ozone is that it does not have a long lasting residual; therefore, it has to be used in combination with another disinfectant. Another disadvantage that has limited the way utilities have been using

ozone over the last years is its reaction with the bromide ion found in some raw waters. This reaction yields bromate, a fairly stable DBP which, at long-term exposure, could increase the risk of cancer¹².

Today there are more than 2,000 UV operating facilities; UV technology has been around since 1910, when it was first used in Marseille, Switzerland. Even though it has been around for almost a century, there are still questions on how UV reacts with drinking water. Currently, it is known that UV inactivates *Cryptosporidium* and *Giardia*, both strong pathogenic organisms difficult to oxidize or inactivate with other disinfectants. Research has shown that UV irradiation does not produce significant DBPs and that it does not lower the water's DBP forming potential, in either treated groundwater or treated surface water¹³. However, it would be impractical to solely use UV in the disinfection process because it does not produce a disinfectant residual.

THM Removal

Directly reducing or removing TTHMs has not been the most popular way to eliminate DBPs. However, two of the technologies that have been successful in reducing the amount of TTHMs are activated carbon and aeration.

Granular Activated Carbon (GAC) can be used to reduce Trihalomethanes or the organic matter precursors from which they are formed. Studies conducted in Greece showed that GAC is "...absolutely efficient in removing TTHMs...". The studies demonstrated that the maximum removal obtained was about 90%, with a minimum removal of approximately 60%¹⁴.

Studies conducted in India with cascade aerators to remove TTHMs yielded a removal efficiency of the unit ranging from 53% to 70%¹⁵.

Henry's Law relates the concentration of a gas in a liquid to the gas pressure. Vapor pressures and Henry's Law Constants for the Trihalomethane compounds of interest are shown in Table 1.

Table 1: Vapor Pressure and Henry's Constant for TTHM compounds¹⁶

Compound	Vapor Pressure, mm Hg @ 20 C	Henry's Constant, Atm-m³/mole @ 20 °C
Chloroform	160	0.00295
Dibromochloromethane	76	0.000642
Bromodichloromethane	50	0.00124
Bromoform	5	0.000358

By applying Henry's Law to the information provided in Table 1, it could be determined that the compounds will most likely volatilize in the following order:

- (1) Chloroform
- (2) Bromodichloromethane
- (3) Dibromochloromethane
- (4) Bromoform

VOC air strippers operate by transferring the volatile compounds from the water phase into the air phase. The efficiency of some of these units has exceeded over 99% percent removal. There are currently many places that are implementing aeration methods to remove volatile compounds^{17,18}.

Procedure

The initial degasification tests were performed using compressed air in various volumes of water: 55 gallons, 500 gallons, and 2000 gallons. Air was released through perforated pipes or air stones at volumetric flow rates between 10 and 25 cubic feet per minute (CFM). The diffused air studies were followed by tests using an induced draft, packed tower at water flow rates up to 64 gallons per minute (gpm) and air flow rates up to 400 CFM. Water was supplied to the tower via a centrifugal pump connected to two 10,000 gallon storage tanks.

Degassing Tower

The water used for all tests was potable water from the Canal Street Water Treatment Plants (Canal Plants) with a minimum free chlorine concentration of 1.5 to 2 mg/L. Two kinds of chlorinated water samples were used in the diffused air and packed tower studies. One consisted of the chlorinated final effluent from the Canal Plant and the other was final effluent spiked with additional chlorine at 10-20 mg/L. Some tests were performed after holding periods of 24 and 48 hours to simulate THM conditions at the most remote part of the distribution system.

The tower used to run the experiments was rented from US Filter. The pilot degasser is the GFC Pilot Plant No. 22*¹. The size of the column was 21 inches square by 17 feet high made of aluminum construction. The depth of the media was 10 feet. The media consisted of 30 cubic feet of Jeager 1.25-inch Tri-Pack balls. The fan used to pull the air up through the tower consisted of a ½ Horse-Power (HP) motor running at 1750 rpm, which produced 2550 CFM of air. The tower was capable of handling water flow rates from 15 to 150 gpm in a counter-current flow pattern.

*¹Information given here for the GFC Pilot Plant No. 22 was provided by US Filter.

Sample Handling

Samples from the 55 gallon, 500 gallon, and 2000 gallon tanks were collected from the top of each tank. The sample was scooped with a beaker and slowly transferred into the sample vials in order to prevent volatilization of the THM's. Samples collected from the packed tower were collected from a spigot at the bottom of the tower.

Dechlorination of the samples was done with granular Sodium Thiosulfate ($\text{Na}_2\text{O}_3\text{S}_2$) and a 1N Sodium Thiosulfate solution as follows:

1. Each sample was collected with a beaker and dechlorinated with the 1N $\text{Na}_2\text{O}_3\text{S}_2$ solution.
2. The samples were then transferred into 40 ml glass vials containing granular $\text{Na}_2\text{O}_3\text{S}_2$ for subsequent THM analysis.

The granular Sodium Thiosulfate was added into the vials to neutralize any remaining chlorine residual to preclude further formation of trihalomethane compounds after the samples were collected.

During the transfer of the sample to the vial, the following precautions were taken to prevent false THM results:

1. The sample was transferred *slowly* from the beaker into the 40 mls vials to prevent any THM compounds from escaping into the atmosphere.
2. Care was taken to ensure that no air bubbles were trapped in the sample (to prevent any THM compounds from escaping into the trapped air during storage).

Immediately after collection, the samples were either stored in a refrigerator or taken to the El Paso Water Utilities Lab for THM analysis. The method used to analyze the samples was 524.2, Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry.

Results and Discussion

Diffused Air Studies

The initial testing was done in a 55-gallon drum, primarily to test the concept of stripping THMs from water using air. Chlorinated river water was used in the tests, with airflow rates ranging from 5 to 20 CFM. The results of THMs remaining versus time for four different aeration rates are shown in Figure 1.

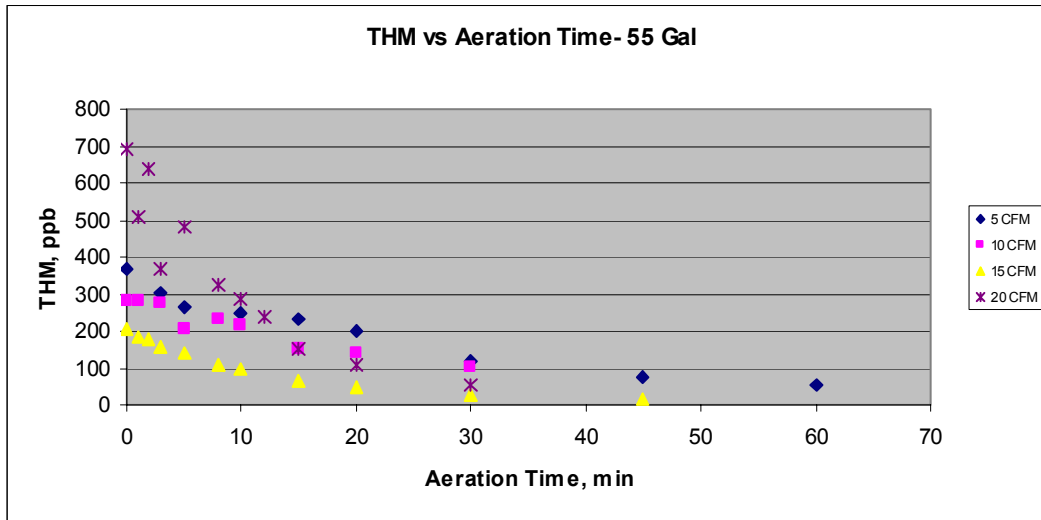


Figure 1 – THMs Remaining vs Time at Four Aeration Rates

The results show that aeration was very effective for removing THMs, especially when the initial THM concentration was very high. The THM concentration remaining appears to be explainable by a first-order equation of the general form:

$$C = C_0 e^{-kt}$$

- Where: C = THM concentration, ppb
 C₀ = Initial THM concentration, ppb
 k = Rate constant
 t = Aeration time, minutes

Figure 2 shows a plot of the equation for the 20 CFM airflow rate. The R² value of 0.97 indicates that the equation represents a very good fit for the data. The R² values for the other three aeration rates were also very high at 0.99, 0.94, and 0.98 for the 5, 10, and 15 CFM aeration rates, respectively. The k values ranged from 0.0319 to 0.0841 for the 5 CFM and 20 CFM aeration rates, respectively.

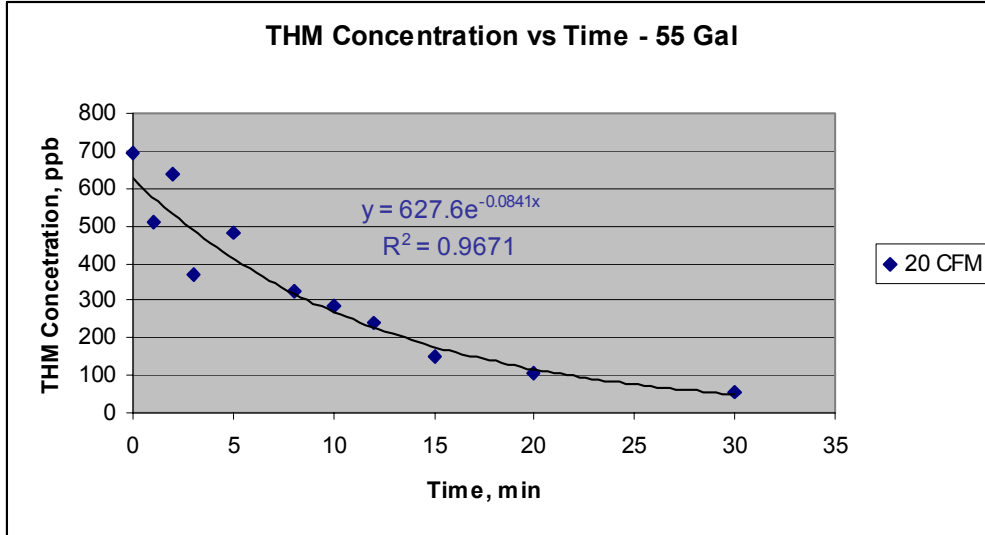


Figure 2 – THM Concentration vs Aeration Time for 20 CFM Aeration Rate

Figure 3 is a plot of *percent* removal versus time for the same data and it shows that the larger percent removals were generally associated with higher aeration rates, as would be expected. At the 20 CFM aeration rate, the removal exceeded 90% after 30 minutes.

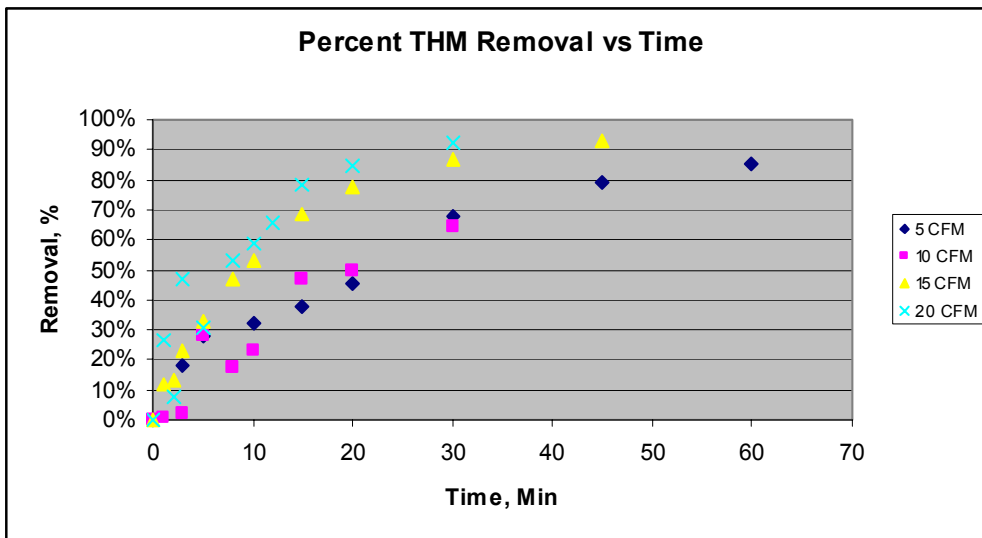


Figure 3 – Percent THM Removal vs Aeration Time – 55 Gallon Drum

The percent removal rates can be modeled via a second-order polynomial equation, as shown in Figure 4 for the 5 CFM aeration rate. Again, high correlation coefficients were obtained for all four aeration rates, with values of 0.95, 0.93, 0.97, and 0.88 for the 5, 10, 15, and 20 CFM rates, respectively.

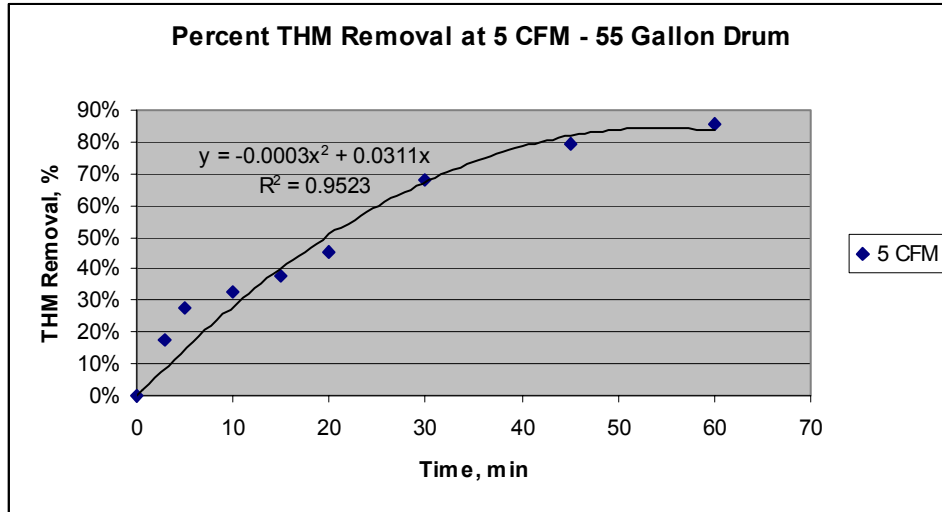


Figure 4 – Percent THM Removal at 5 CFM – 55 Gallon Drum

The second set of tests was conducted in a 500-gallon plastic day tank. The removal curves were similar in shape to those obtained in the 55-gallon drums, as shown in Figures 5 and 6.

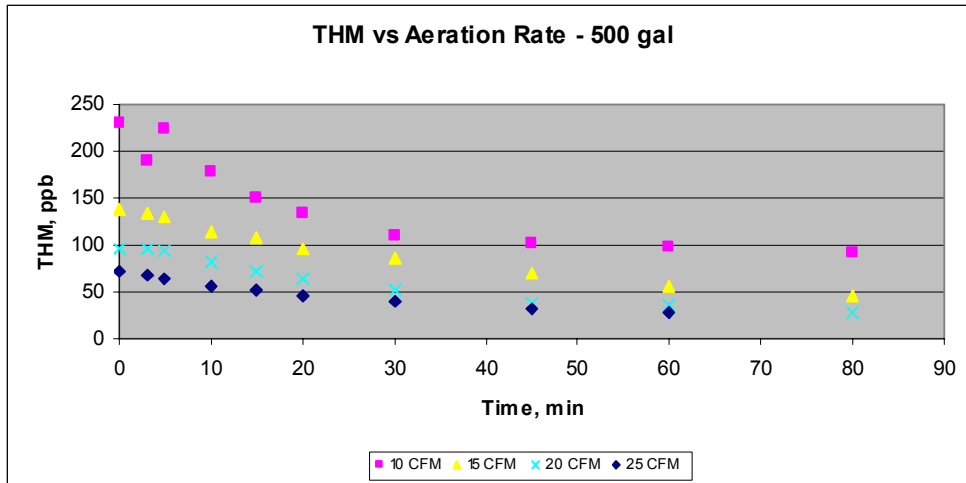


Figure 5 – THM Concentration vs Aeration Time – 500 Gallon Tank

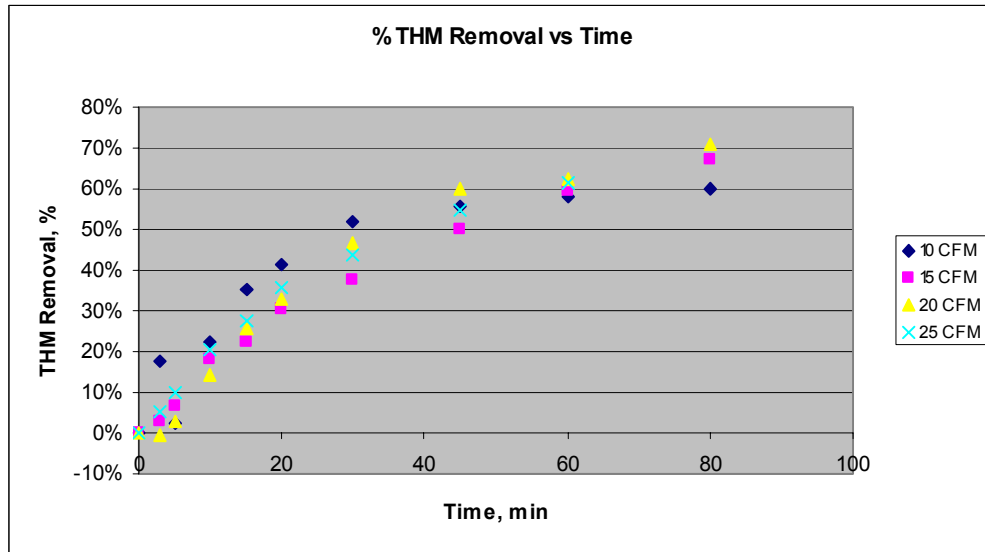


Figure 6 – Percent THM Removal vs Aeration Time – 500 Gallon Tank

The correlation coefficients for the exponential equations for the data in Figure 5 were as high as those from the 55-gallon drum, with values of 0.83, 0.99, 0.96, and 0.98 for the aeration rates of 10, 15, 20, and 25 CFM, respectively. However, the k values were lower because of the reduced air:water volume ratio, with a range of values from 0.0118 to 0.0165. These lower values are manifested in lower THM removal rates for a given time period. For example, the THM removal at an airflow rate of 15 CFM for 45 minutes was over 90% in the 55-gallon drum, but it was only 50% in the 500-gallon tank. Similar differences can be observed in Figures 3 and 6 for other air flow rates and other aeration times.

The final set of diffused air studies was conducted in a 2000-gallon plastic tank. The results are similar to those discussed previously for the smaller tank volumes.

Induced Draft Packed Column Studies

The packed column degassing studies were conducted at water flow rates ranging from 6.7 to 68 gpm. For the 3.09 ft² cross-sectional area, these rates correspond to hydraulic loading rates of 2.2 to 22 gpm/ft². The airflow rates were varied from 0.02 to 0.18 inches of water, which correspond to volumetric airflow rates of 100 to 550 cfm, or 32.4 to 178 cfm/ft². These rates produced air:water ratios ranging from 188:1 to 342:1.

Figure 7 shows percentage THM removals for various study conditions, with the legend indicating the magnitudes of the water flow rates and the initial THM concentrations (low, medium or high). A “low” THM concentration was considered to be below 80 ppb, “medium” up to 150 ppb, and “high” above 150 ppb.

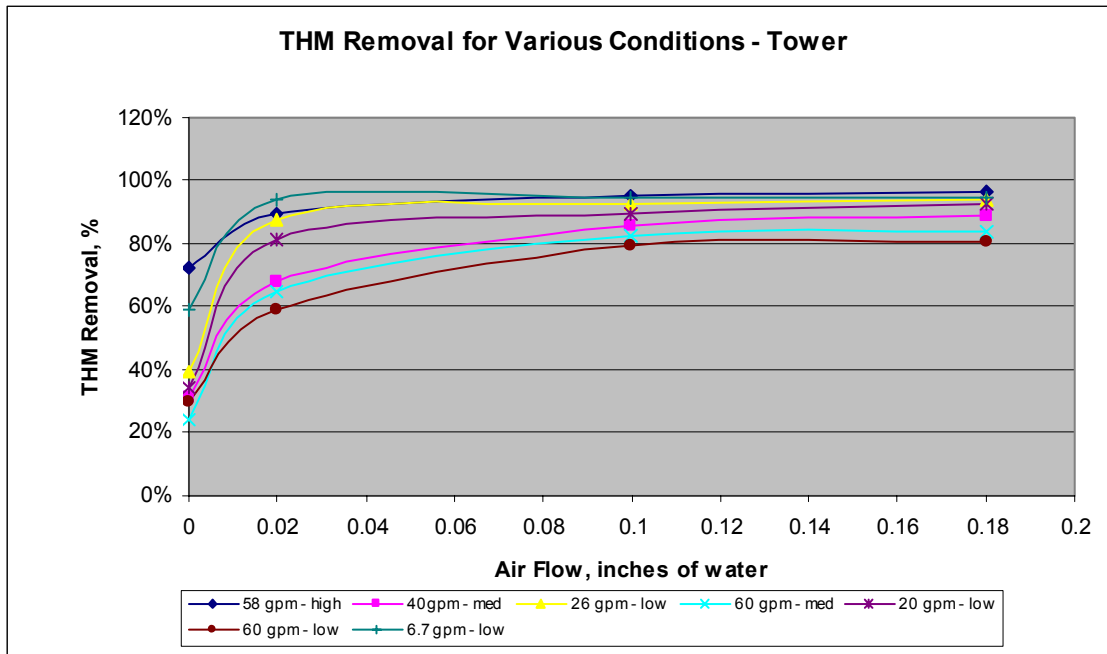


Figure 7 – THM Removals in Degassing Tower

The graph clearly shows that THM removal increases as the airflow rate increases, with removal efficiencies exceeding 95% in some cases. It also shows that the higher removal percentages are associated with either low water flow rates or high initial THM concentrations. Figure 7 also shows that even when the induced air fan was turned off (i.e. 0 airflow rate), some THM removal occurred, especially when the water flow rate was very low or the initial THM concentration was very high. The removal percentages at 0 airflow rate ranged from 24% (60 gpm, 104 initial THM) to 89% (6.4 gpm, 98.4 initial THM).

Figure 8 is a plot of THM removals as a function of water flow rate for three different runs and it shows that the removal efficiency decreases from about 95% at the 6.7 gpm water flow rate to between 70 and 80 % at the 64 gpm flow rate.

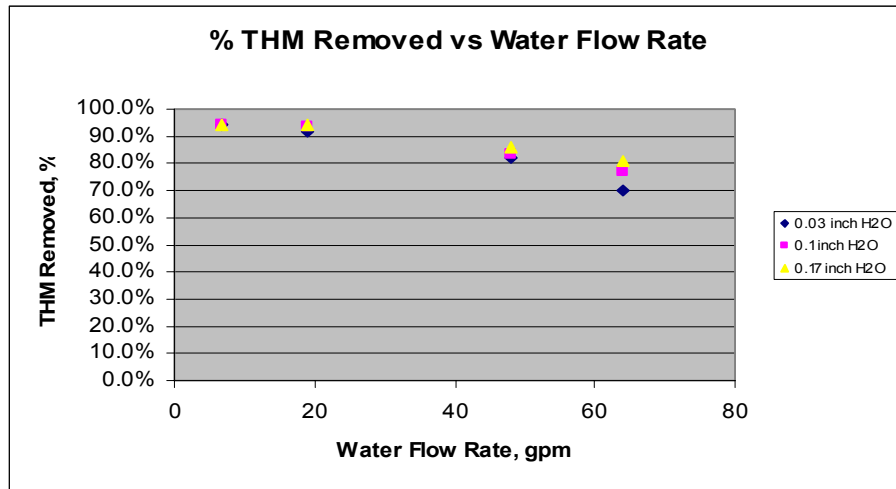


Figure 8 – THM Removal as a Function of Water Flow Rate

A more meaningful THM removal parameter than water flow rate is air:water ratio. Figure 9 is a plot of air:water ratio versus percent THM removal for a wide range of air and water flow conditions and, as shown, the highest removals are associated with ratios above a value of about 60.

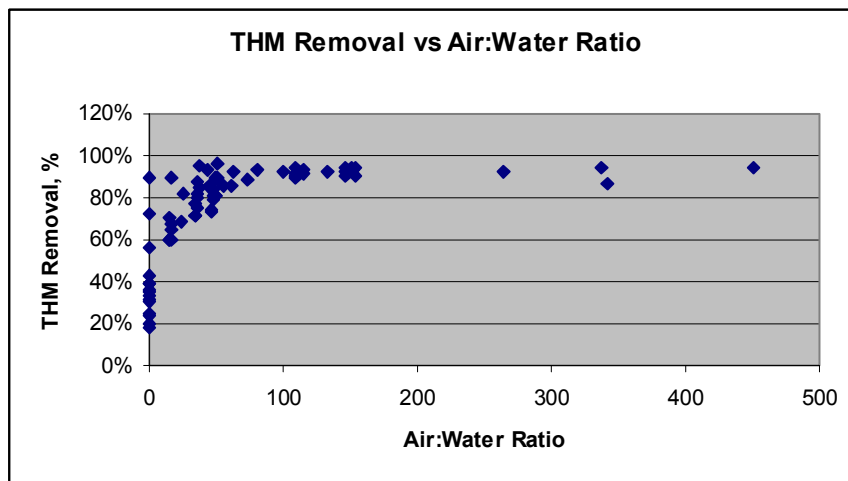


Figure 9 – Effect of Air:Water Ratio on % THM Removal

The effect of initial THM concentration on percent removal is shown in the graph of Figure 10. The graph is a plot of three of the highest water flow rates (58 – 60 gpm) having three different initial THM concentrations (68, 104, and 471 ppb). The graph shows that, at all three airflow rates, the higher the initial THM concentration, the higher the percent removal. This is consistent with the first-order nature of THM removal as discussed in the diffused air section of this report.

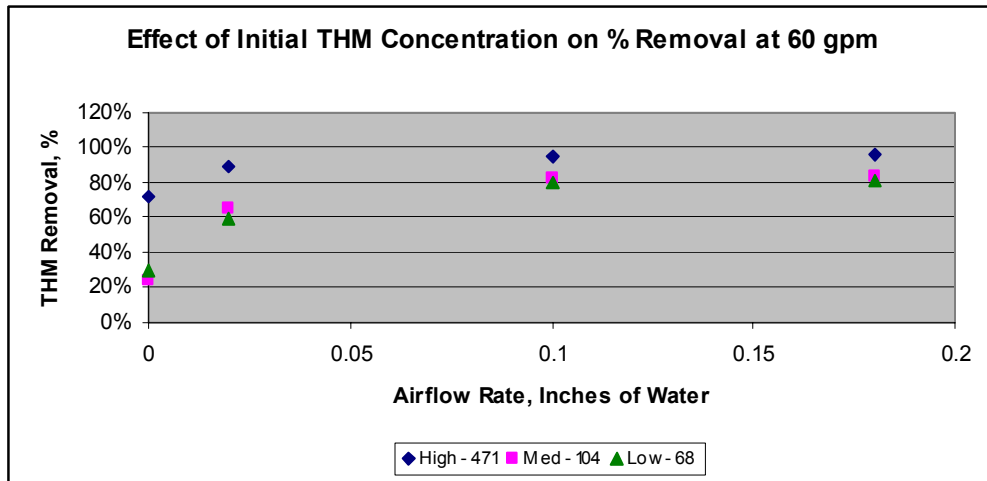


Figure 10 – Effect of Initial THM Concentration on Removal

In order to determine the effect of THM degassing on chlorine residual, samples were taken from the tower influent and effluent on four different occasions and analyzed for free chlorine and total chlorine residual. The averaged results of the total chlorine analyses are presented in Figure 11 and, as the graph shows, there was no discernable difference in the chlorine concentration between the influent and effluent samples. This means that chlorinated water could be degassed without fear of reducing the chlorine residual in the product water after it has left the water treatment plant.

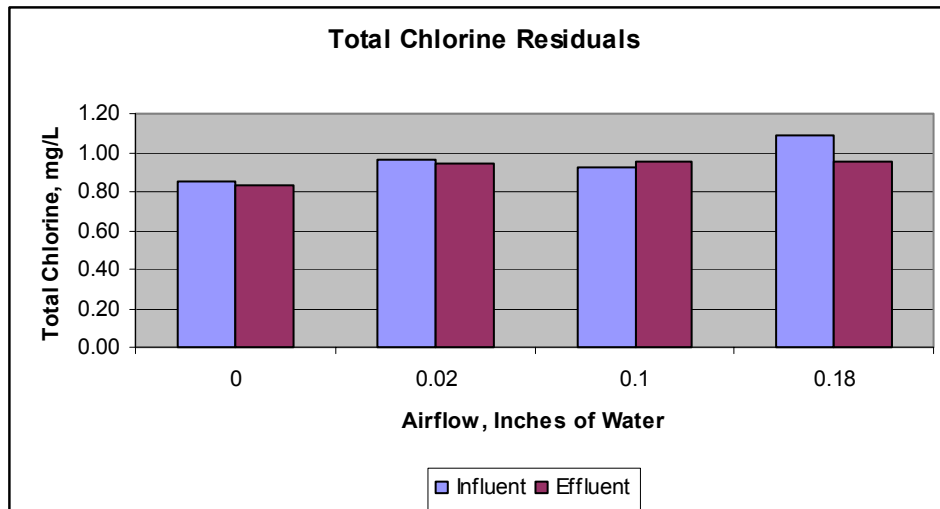


Figure 11 – Total Chlorine Concentrations in Tower Samples

Temperature, pH, and Alkalinity data were in rather narrow ranges, with temperature ranging from 24 – 32.5 °C, pH from 7.3 – 8.4, and Alkalinity from 132 – 148 mg/L.

The effectiveness of stripping the individual THM compounds is shown in Figure 12. These results are for a water flow rate of 22 gpm with no air and they show the general pattern of highest removal for chloroform and lowest for bromoform. Percentage removals with air ranged from 69% to 96% for chloroform and 32% to 87% for bromoform.

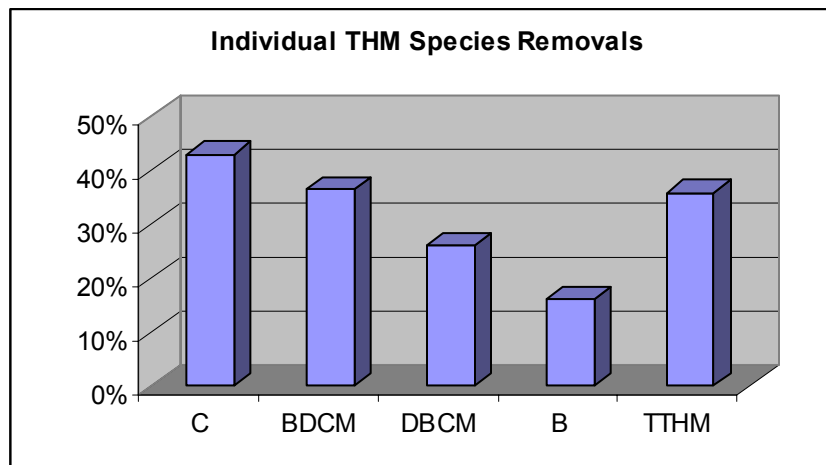


Figure 12 – Individual THM Species Removals

Economic Considerations

The economic calculations presented in this section are for packed column degassing only. This is because the diffused air systems employed in this study were used primarily for demonstrating proof-of-concept and, as such, were highly inefficient and not cost competitive.

The packed column costs are based on a treated water volume of 1 MGD. The capital cost items include the degassing tower, piping, and other appurtenances needed for installation. The operating costs are for water pumping and airflow generation. Some of the cost items used in these calculations are estimated values and, therefore, are subject to change. Therefore, all calculations were made using both best-case and worst-case scenarios. As a worst case, the capital cost was amortized over 10 years at the highest value of the estimated cost range (i.e. \$25,000 - \$100,000), even though the

actual cost is likely to be lower and the major cost items of the packed tower will likely last much longer than 10 years. Also, it was assumed that the degassing column will be operated 24-hours per day at the highest airflow rate tested (this is unlikely because the THM reduction would exceed over 80%, and that much reduction is not needed).

Worst-case scenario:

Capital Cost: \$100,000

Assume 10-year life of equipment and interest rate of 5% per year:

$$\begin{aligned} AW &= 100,000(A/P, 5\%, 10) \\ &= 100,000(0.12950) \\ &= \$12,950 \text{ per year} \end{aligned}$$

$$\begin{aligned} \text{At 1 MGD flow, cost/1000 gal} &= 12,950 / (1,000,000 * 365) / 1000 \\ &= \$0.035 \end{aligned}$$

Operating Cost:

Water Pumping:

For worst case, assume 24 hr/day operation: H = 20'; Q = 700 gpm; E = 75%

$$\begin{aligned} P &= G * H / 3960 * E \\ &= 700 * 20 / 3960 * 0.75 \\ &= 4.71 \text{ HP} \end{aligned}$$

$$\begin{aligned} \text{Power Cost} &= 4.71 \text{ hp} * 0.75 \text{ kw/hp} * 24 \text{ hrs/day} * 0.06 \text{ \$/kw-hr} \\ &= \$5.08 \text{ per day} \end{aligned}$$

$$\begin{aligned} \text{Cost/1000 gal} &= 5.08 / (1,000,000 / 1000) \\ &= \$0.00508 \\ &= 0.5 \text{ cents/1000 gal} \end{aligned}$$

Air Flow:

For worst case, assume max airflow is needed: ½ HP in test column at 64 gpm

$$\begin{aligned} \text{Power Cost} &= 0.5 \text{ hp} * 0.75 \text{ kw/hp} * 24 \text{ hrs/day} * 0.06 \text{ \$/kw-hr} \\ &= \$0.54 \text{ per day} \end{aligned}$$

$$\begin{aligned} \text{Cost/1000 gal} &= 0.54 \text{ \$/day} / [(64 \text{ gal/min} * 60 \text{ min/hr} * 24 \text{ hrs/day}) / 1000] \\ &= \$0.00585 \\ &= 0.6 \text{ cents/1000 gal} \end{aligned}$$

Total Operating Cost = Water pumping cost + air generation cost

$$= 0.5 + 0.6$$

$$= 1.1 \text{ cents /1000 gal}$$

Total Cost = capital cost + total operating cost

$$= 3.5 + 1.1$$

$$= 4.6 \text{ cents/ 1000 gal (worst case)}$$

Thus, under the worst-case scenario that was assumed here, the total cost for degassing THMs would be 4.6 cents per thousand gallons of treated water.

For the best-case scenario, the capital cost was assumed to be \$25,000, a 20-year amortization period was used, and an 8-hour operating day was assumed. The calculations for these conditions are as follows:

Best-case scenario:

Capital Cost: \$25,000

Assume 20-year life of equipment and interest rate of 5% per year:

$$AW = 25,000(A/P, 5\%, 20)$$

$$= 25,000(0.08024)$$

$$= \$2,006 \text{ per year}$$

$$\text{At 1 MGD flow, cost/1000 gal} = 2,006 / (1,000,000 * 365) / 1000$$

$$= \$0.0055$$

$$= 0.55 \text{ cents/1000 gal}$$

Operating Cost:

Water Pumping:

For best case, assume 8 hr/day operation: H = 20'; Q = 700 gpm; E = 75%

$$P = G * H / 3960 * E$$

$$= 700 * 20 / 3960 * 0.75$$

$$= 4.71 \text{ HP}$$

$$\text{Power Cost} = 4.71 \text{ hp} * 0.75 \text{ kw/hp} * 8 \text{ hrs/day} * 0.06 \text{ \$/kw-hr}$$

$$= \$1.69 \text{ per day}$$

$$\text{Cost/1000 gal} = 1.69 / (1,000,000 / 1000)$$

$$= \$0.0017$$

$$= 0.17 \text{ cents/1000 gal}$$

Air Flow:

For best case, assume max airflow is needed: ½ HP in test column at 64 gpm

$$\begin{aligned}\text{Power Cost} &= 0.5 \text{ hp} * 0.75 \text{ kw/hp} * 8 \text{ hrs/day} * 0.06 \text{ \$/kw-hr} \\ &= \$0.18 \text{ per day}\end{aligned}$$

$$\begin{aligned}\text{Cost/1000 gal} &= 0.18 \text{ \$/day} / [(64 \text{ gal/min} * 60 \text{ min/hr} * 24 \text{ hrs/day}) / 1000] \\ &= \$0.002 \\ &= 0.2 \text{ cents/1000 gal}\end{aligned}$$

$$\begin{aligned}\text{Total Operating Cost} &= \text{water pumping cost} + \text{air generation cost} \\ &= 0.17 + 0.2 \\ &= 0.37 \text{ cents /1000 gal}\end{aligned}$$

$$\begin{aligned}\text{Total Cost} &= \text{capital cost} + \text{total operating cost} \\ &= 0.55 + 0.37 \\ &= 0.92 \text{ cents/ 1000 gal (best case)}\end{aligned}$$

The total cost for degassing under best-case conditions is only 0.92 *cents* per thousand gallons of water, which is approximately 1/5 of the worst-case cost. A realistic cost will lie somewhere between these two extremes, but will probably be closer to the best-case value.

Conclusions

Based on the results of this investigation, the following conclusions can be made with reasonable certainty:

1. Trihalomethanes can be air-stripped from water very effectively using either a diffused air system or a packed-bed degassing column. In these studies, a degassing column was clearly the best option, with overall efficiencies ranging from 59% to 96%.
2. Trihalomethane removal from water via diffused air-stripping appears to follow first-order kinetics. Therefore, high concentrations of THMs can readily be reduced using air-stripping methods.
3. THM removal in an induced-draft packed column is a function of the initial THM concentration, the water flow rate, and the airflow rate, with the higher removals (90–96%) generally associated with air-to-water ratios greater than 60.
4. Chlorine residual was generally unaffected by the packed bed degassing operation.
5. Individual THM species were stripped in different amounts, with chloroform the easiest to remove and bromoform the hardest.
6. A packed bed column appears to be a very cost-effective method for removing THMs from water. The cost under best-case and worst-case scenarios was 0.92

cents per thousand gallons to 4.6 *cents* per thousand gallons of treated water, respectively.

In general, THM stripping via an induced draft packed column appears to be an excellent method for meeting the THM standard in drinking water. The operation is simple, highly efficient, and appears to be very cost-effective.

Recommendations

The favorable results obtained in this study clearly indicate that an induced draft packed column is an efficient, cost-effective method for removing trihalomethanes from water. Therefore, implementation on a full-scale level is warranted and is highly recommended.

Acknowledgements

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