AWWA Ohio Section
Technology Committee

White Paper on Aeration to Reduce Trihalomethanes

November 30, 2013

1. Introduction

With the implementation of Stage 2 – Disinfectants/Disinfection Byproducts Rule and increased public concern about disinfection byproducts (DBPs) and chemicals in general, water systems are searching for alternative methods to reduce disinfection byproducts to maintain compliance and to reduce public exposure to DBPs. The primary method for reducing DBPs is to reduce natural organic matter (NOM) via treatment processes at the water treatment plant prior to chlorination. Another method for reducing DBP levels is the reduction of previously formed DBPs in the distribution system. Distribution systems with high water age, especially consecutive systems, are particularly prone to excessive THM concentrations.

Research has shown that trihalomethanes (THMs), one group of DBPs, are very susceptible to removal by aeration while not significantly reducing existing chlorine residual levels. Aeration practiced in distribution systems have been shown to be very cost effective when compared to major changes in treatment processes or alternate disinfection practices that may also present unintended water quality consequences. In addition, aeration seems to be most effective on waters containing high THM levels including water systems with high water age and consecutive systems.

For haloacetic acids (HAAs) another group of DBPs, aeration has not been shown to be an effective removal process and in some instances HAAs have been seen to actually increase with aeration.

Three general forms of aeration have been used; diffused air, spray nozzle, and surface aeration. Typical applications include: clearwells at the treatment plant which treat all of the system's water and storage tanks at strategic points in the distribution system.

The focus of this white paper is on reduction of previously formed THMs by aeration, to provide guidelines for aeration system implementation, provide factors that must be considered prior to implementation, and establish criteria for Ohio EPA plan approval submission.

2. Formation of Trihalomethanes

Trihalomethanes are formed by the chemical reaction of chlorine and NOM. Chlorine sources include gaseous chlorine, sodium hypochlorite, calcium hypochlorite, chloramine, and chlorine dioxide. Water quality parameters that exacerbate THM formation include; high NOM concentration, high water temperature, long detention time, high pH, high bromide levels, and high chlorine dosage. With exception of water temperature and bromide levels, operators have varying degrees of control over the other parameters. However, costs, other regulations, and competing water quality goals can limit the ability to control the other parameters. Systems are encouraged to optimize treatment, and control water age through pumping schemes and distribution storage turnover to reduce THM formation prior to implementing a THM removal strategy. Systems practicing optimization will see a wide range of benefits including reduced THM and other DBP formation.

THMs are volatile organic compound (VOCs) gasses dissolved in water. Because they are volatile, the aeration process can be used to transfer VOCs from the water phase to the air phase. Henry's Law describes the relationship of the concentration of a gas in a liquid to the gas pressure. The higher the Henry's constant, the more readily the compound can be transferred from water to air as shown in the following equation.

$$C_{gas} = H \times C_{aqueous}$$

Where: C_{gas} = VOC concentration gas phase
H = Henry's Constant
$C_{aqueous}$ = VOC concentration liquid phase.

It should be noted that the Henry's Constant for a compound is dependent upon and in proportion to temperature. The higher the water temperature, the greater the constant, and therefore increasing VOC removal potential.

Total trihalomethanes (TTHMs) are some of the parameters regulated in Stage 2 D/DBP Rule. The reported TTHM concentration is the sum of four different THM species; trichloromethane (chloroform), bromodichloromethane, dibromochloromethane and tribromomethane (bromoform). The Henry's Constant for each compound is listed in the following table from highest (easiest to remove) to lowest.

Compound	Henry's Constant Atmospheres @ 20 deg C
Chloroform	170
Bromodichloromethane	118
Dibromochloromethane	47
Bromoform	35

As noted above, chloroform, with the greatest Henry's Law Constant, is the easiest THM to remove from water with bromoform, having the smallest Henry's Law Constant, being the most difficult of the four THM species. Most systems have chloroform as the predominant THM species thereby making it the primary target of aeration reduction. However, properly designed aeration systems may also successfully remove the brominated compounds as well. The Henry's Constant provides a general expected "capability for volatilization"; it does not necessarily imply an expected THM reduction of any individual species or a relative expected reduction of any individual species compared to the other regulated THM species.

Several mathematical models of the aeration process are available to calculate removal efficiencies of different THM species. For further information on these models, see the list of references section.

3. Design Considerations

Since aeration may only reduce preformed THMs and not reduce formation potential, historical flow, residence time and THM data from the proposed tank are necessary considerations for system design. The water system should consider the impact of tank aeration to water quality in the immediate area as well as hydraulically downstream from the tank. A computer distribution model will be beneficial for use as a tool to estimate the affected downstream users. The system should also consider the contribution of the tank and the impact of tank aeration on THM concentration on the Stage 2 sampling sites.

Tank aeration may also affect water quality parameters such as pH, alkalinity, free chlorine residual and stability. Aeration systems may change pH and alkalinity thereby affecting stability. Chlorine residuals may be affected and the water system should be aware of this phenomenon and monitor accordingly.

Water systems are dynamic in that there are many operating parameters that affect water quality in storage tanks such as flow rates, tank turnover, water depth, minimum freeboard, and fresh air exchange rate. Flow rate and tank turnover control the age of water in a tank with age being important to minimize to achieve better water quality. Water depth in a tank is important to avoid stagnant areas and will affect the volume of water that can be influenced by an aeration system. Minimum headspace between the water level in a tank and the top of the tank will have a dramatic effect on the efficiency of spray aeration systems which need both unsaturated air and distance between nozzle and water surface to allow transfer of the THMs. The geometry of the tank and baffling (if present) within the tank should be considered in the selection and design of an aeration system.

Spray aeration systems draw water from the bottom of the tank and spray from a nozzle into the airspace of the tank above the water surface. The water sprays droplets a distance through the air, before landing on the surface of the water. THM reduction efficiency is affected by droplet diameter, droplet travel distance and water temperature. In spray aeration, the water droplet travels in air rather than through water. As the droplet passes through air, it is constantly in contact with air containing THMs at concentrations well below equilibrium levels. Therefore, there is a constant and large driving force favoring THM stripping, and as long as the droplet passes through a sufficient unsaturated air path length. The differences in Henry’s Law Constants between THM species will not lead to significant differences in percent reduction between species.

Diffused air systems diffuse air into a tank in the form of tiny bubbles, which travel up through the water column creating air to water contact. THM reduction is affected by air bubble diameter, air to water ratio, depth of water above the diffusor, detention time and water temperature. The geometry of the tank and baffling (if present) within the tank should be considered in the selection and design of a diffused air aeration system.

Surface aeration systems include a pump, mixer, or piping arrangement used singly or in combination to transfer water from the bottom of the tank to the surface where the mass transfer occurs. Pump(s) or mixer(s) may float on the surface, be mounted to the bottom of the tank or be located external of the tank. Since the water only needs to be lifted to the water surface, energy input is comparatively low. Like other aeration systems, effectiveness of THM reduction depends upon design factors such as air to water ratio, water detention time and water temperature. Adequate headroom must be available above the water surface in the tank to install a surface aeration system.

Any aeration system will promote the transfer of THMs from the liquid phase into the air above the water level in the tank. Proper ventilation is required so that air in the tank will not become saturated with THMs thereby reducing the efficiency of THM transfer. Typically, existing storage tank ventilation systems are designed to provide inlet/exhaust air as required to match water drawdown/fill flow rates. Properly positioned fans may be required to promote fresh air turnover.

Expected THM reduction is site specific and depends upon a number of chemical and operational parameters. Recent studies have shown a practical expectation could be 20%-70% reduction in THMs. Design considerations should evaluate system-wide elevated THM levels versus locational elevated THM levels. System-wide levels may be more economically addressed through treatment modifications. However, some research has shown aeration in a clearwell can be effective if THM formation has already occurred. Locational THM levels, such as those in a separate distribution system zone directly impacted by a storage tank, may be more economically addressed through tank operational changes and/or aeration if the THMs have already formed.

Some proprietary aeration systems include tank mixing as a means to reduce stratification and create uniform average detention times throughout the tank. The mixing action can promote continuous air - water interface at the water surface thereby reducing THMs. Because of the limited mixing action typically induced by these systems, the air – water interface is typically much less than in other aeration systems and actual THM reduction will be less. In general, tank mixing is a distribution system best management practice which, if done properly, can result in reduction or elimination of dead zones, reduce THM formation, increase chlorine residual and improve water quality and increase aeration effectiveness. While providing mixing in a largely stratified tank can improve the overall water quality, in some storage tanks, the addition of tank mixing systems may increase water age hydraulically downstream from the tank.

4. Ohio EPA Plan Approval

Ohio EPA plan approval is required for all new tank aeration systems. The plan approval submission shall comply with Ohio Administrative Code 3745-91. Ohio EPA does not view aeration as an emerging technology. As a result, demonstration or pilot studies are no longer required prior to obtaining detail plan approval under normal conditions.

Plan approval submission should include:

- Water treatment plant capacity and historical production data. Consecutive systems shall provide historical flow data at the connection point with the source system.
- Tank dimensions and overflow elevation.
- Historical water levels and typical operating range.
- Historical THM data at or near the location where the aeration system is to be placed.
- Skeletonized distribution system map showing Stage 2 sampling sites and location of tank where the proposed aeration system will be installed.
- Aeration system design parameters including: pump, mixer, blower, and exhaust/inlet fan capacity and horsepower; piping arrangement, diffusor details including orifice size, number and area covered; air to water ratio; and spray nozzle details, and number of nozzles.
- Tank drawing noting: existing and proposed air inlet/exhaust ventilation locations; proposed diffusor location; pump(s) and nozzle(s) location; and mixer location if applicable.
- Equipment anchoring details inside the tank, including any tank penetrations.
- TTHM reduction goals of the project.

In addition to the above, it is recommended the following information be submitted with the detail plan approval package if available:

- Vendor data from similar applications or test data noting water analysis before and after aeration.
- On-site testing of the aeration system.

5. Summary

Aeration of finished chlorinated water has been successfully used to reduce THMs after their formation. Haloacetic acids, on the other hand, will not be reduced by aeration and under the right conditions could increase. Aeration should not be used as a substitute for reducing disinfection byproduct precursors and formation potential at the treatment plant. Water systems should also perform best management practices in the distribution system to exercise tanks, reduce water age, control chlorine residuals, periodically clean storage tanks, and perform routine hydrant flushing.

A variety of aeration methods are available and the success of each method is influenced by specifics of the application. Tank turnover, availability of proper headspace, tank venting, and other factors can highly influence how well the system works.

Aeration also has been noted to affect other water quality parameters including pH, water stability and maintenance of chlorine residuals. A successful implementation of aeration should consider these unintended consequences and the water quality should be closely monitored after the installation of an aeration process.

6. List of References

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