

☠ CHLORINE ☠



Disinfection Byproducts and Waterborne Disease: The Need For *Balance* Is Essential

By Vipin Bhardwaj • NESCE Engineering Scientist

Using chlorine to disinfect drinking water was the single, most important public health practice in preventing waterborne diseases in the 20th century. Disinfection has virtually eradicated a number of waterborne diseases, such as typhoid, cholera, and dysentery, and has literally saved millions of lives. But all of the news about chlorine isn't good.

In 1974, J.J. Rook discovered that free chlorine reacts with organic matter and forms a wide range of substances known as disinfection byproducts (DBPs). The reaction happens when naturally occurring carbon compounds, such as decayed vegetation, fish, or aquatic organisms, disintegrate. Other chlorine-based disinfectants, such as chloramines and chlorine dioxide, also may form DBPs.

Some of these DBPs can cause cancer, as shown in experiments on animals in laboratory studies, and others can cause acute health

problems, such as liver damage. The discovery of DBPs and their adverse health effects highlights the necessity for better understanding the disinfection process. And, it also means that researchers must strike a balance between preventing waterborne disease and the health effects that DBPs cause.

Types of Disinfection Byproducts

When chlorine reacts with organic matter, hundreds of DBPs may form. Two major classes make up the bulk: trihalomethanes (THMs) and haloacetic acids (HAA).

THMs include chloroform, bromoform, bromodichloromethane, and dibromochloromethane. HAAs are commonly abbreviated as HAA5, and include chloroacetic acid, dichloroacetic acid, trichloroacetic acid, bromoacetic acid, and dibromoacetic acid.

Although THMs and HAAs are the major DBPs, there are a variety of other disinfection compounds, such as haloacetonitriles, halo ketones, haloaldehydes, chloropicrin, cyanogen chloride, and chlorophenols.

Recently, alternative disinfectants, such as chloramines, chlorine dioxide, and ozone, also have been found to react with organics and can form DBPs.

Health Effects of Disinfection Byproducts

THMs

The four THMs are regulated together as total trihalomethanes (TTHMs). The current maximum contaminant level (MCL) for THMs is 0.080 milligrams per liter (mg/L). The sum of the concentrations of each compound cannot exceed 0.080 mg/L. Samples are taken quarterly and the average of the four samples must not exceed 0.080 mg/L.

Chloroform affects liver and kidney function in humans in both acute and chronic exposures. In lab studies on mice and rats, three THMs, bromoform, bromodichloromethane, and dibromochloromethane caused changes in kidney, liver, and serum enzyme levels and decreased body weight.

Haloacetic Acids

Dichloroacetic acid (DCA) and trichloroacetic acid (TCA) are found more often among the HAA5s. The MCL for HAA5s as a whole group is 0.060 mg/L.

The U.S. Environmental Protection Agency (EPA) has classified DCA as a human carcinogen. Human exposure studies indicated that people exposed to DCA for six to seven days at 43 to 57 mg/kg/day showed mild sedation, reduced blood glucose, reduced plasma lactate, reduced plasma cholesterol, and reduced triglyceride levels. Studies in mice and rats showed that it causes liver tumors.

Studies have shown that TCA can produce developmental malformations in rats, particularly in cardiovascular systems.

What do the regulations say?

The Stage 1 Disinfectants and Disinfection Byproducts Rule took effect on January 1, 2004, and applies to community water systems and non-transient non-community systems, including those serving fewer than 10,000 people that add a disinfectant during any part of the treatment process. In addition, a Stage 2 DBPs Rule has been proposed to supplement the Stage 1 DBP Rule. It will require systems to comply with a DBP MCL at each location of the monitoring site.

The Stage 1 DBP Rule applies to all systems that add chlorine, chloramines, or chlorine dioxide as a disinfectant. It requires new maximum residual disinfectant levels (MRDLs) for chlorine (4 mg/L), chloramines (4 mg/L), and chlorine dioxide (0.8 mg/L). MRDLs are like MCLs that are applicable to disinfectants. The MRDLs keep disinfectant levels low enough to minimize DBP formation and limit health effects.

The rule specifies MCLGs for four trihalomethanes:

- chloroform (zero),
- bromodichloromethane (zero),
- dibromochloromethane (0.060 mg/L),
- bromoform (zero).

Chlorine is hard to beat when it comes to disinfecting. The operators at Tygart Valley Water Plant take all of the necessary precautions when dealing with their chlorine disinfection system.



Photo by Julie Black

Two groups of haloacetic acids:

- dichloroacetic acid (zero) and trichloroacetic acid (0.3 mg/L),
- bromate (zero) and chlorite (0.8 mg/L).

The rule requires treatment techniques to remove natural organic matter and specifies MCLs for:

- total trihalomethanes—the sum of the four listed above (0.080 mg/L),
- haloacetic acids (HAA5) (0.060 mg/L)—the sum of the two listed above plus monochloroacetic acid and mono- and dibromoacetic acids, and
- two inorganic disinfection byproducts (chlorite (1.0 mg/L) and bromate (0.010 mg/L).

The Stage 1 Rule requires systems to develop a monitoring plan that outlines schedules for collecting samples and their locations. The plan must cover the entire distribution system. The number of people that the system serves determines sampling frequency. Table 1 gives the frequency of samples.

Compliance is based on the running annual average (RAA) of monthly averages of all compliance samples collected in the last 12 months. Compliance must be calculated each quarter, using the results from the previous 12 months. Any RAA of monthly averages that exceeds the MRDL is a violation.



Photo by David B. Fankhauser, Ph.D., <http://biology.clc.ucc.edu/fankhauser/>

Stage 2 Rule

The Stage 2 DBP Rule goes a step further. It requires systems to evaluate themselves and identify locations within their distribution systems that have higher residence time or pockets of water that stay in the distribution system longer. Samples would have to be taken at these sites. EPA calls this process initial distribution system evaluation (IDSE). Under the Stage 2 DBP Rule, MCLs for TTHMs and HAA5s will be calculated at each monitoring site. This is known as a locational RAA, (i.e., running yearly averages of each sample collected at the specified location).

The Stage 2 Rule is more difficult for systems to comply with because DBP levels in some parts of a distribution system can be higher than when water is standing at one point. The Stage 2 Rule is expected to take effect by 2005.

Methods to Treat DBPs

There are four approaches to alleviate DBPs:

1. minimizing precursors,
2. reducing disinfectant doses,
3. removing DBPs after their formation, and
4. using alternative disinfectants.

Minimizing Precursors

One way to prevent DBPs is to prevent the occurrence of natural organic matter in the source water. System operators can:

- reduce the precursor content of raw water, such as blending source waters,
- remove precursors in the plant,
- disinfect the water after all other treatment has been completed, or
- a combination of the three.

Adsorption with granular activated carbon (GAC) and coagulation with alum and ferric salts may reduce natural organic matter levels.

Reducing Disinfectant Dosages

Reducing the primary and secondary disinfection dosages and introducing booster chlorination later in the distribution system can reduce the overall disinfectant dosage. Eliminating prechlorination altogether also will prevent organic matter from coming in contact with chlorine. Also, including an anthracite layer in the filter or feeding activated carbon before the filtration step will adsorb organic matter before filtration. Chlorination can then be performed later.

Removing Disinfection Byproducts

EPA identified enhanced coagulation, enhanced softening, or granular activated carbon as the best available technologies (BATs) for removing THMs and HAAs. However, these methods are expensive and must be used only after other methods have been tried. GAC adsorption method requires long columns with substantial carbon content.

Alternative Disinfectants

Alternative disinfectants are ultraviolet light (UV), potassium permanganate, ozone, or a combination of chlorine dioxide and chloramines.

Chlorine gas is inexpensive and effective. None of the other disinfectants are as economical as chlorine. Ozone is a powerful disinfectant, which does not produce chlorinated organics but does create other byproducts. Additionally, ozone does not have a residual so it is used along with chloramines that



Photos Source: Wilsonville, Oregon Water Treatment Plant

Wilsonville, Oregon, is a city of approximately 14,000 people. Their water treatment plant, located on the Willamette River, has enhanced methods of water treatment incorporated into the design of their multi-barrier system, which includes an ozonation disinfection process.



Photos Source: Wilsonville, Oregon Water Treatment Plant

Liquid oxygen is used to generate ozone for the treatment process. The machine pictured above converts the oxygen gas (O_2) into ozone (O_3). After the ozone is bubbled through the water in the treatment process, the ozone is converted back to oxygen gas and released to the atmosphere. For more information visit their Web site at www.ci.wilsonville.or.us/departments/pw/water/WRWTP.htm.

provide a residual. When UV disinfection is used, it also has the same problem of no residual, and chloramines or chlorine is used for the residual. UV is not effective for turbid waters, and UV effectiveness decreases with increasing turbidity.

Some states do not recognize other disinfectants and will not approve them unless they are used along with chlorine or chloramines that provide a residual. Systems need to check with their primacy agencies before selecting alternative disinfectants.



Photos Source: Snodland Town, Kent, England Drinking Water Services

Snodland Town, Kent, England has a population of approximately 9,000. The town installs a variety of small water treatment systems to meet individual needs. A wide range of disinfection options are offered including small UV treatment units, filters, and monitors.



Photos Source: Snodland Town, Kent, England Drinking Water Services

For more information visit their Web site at www.drinking-water.co.uk/index.htm.

Chlorine Is Hard to Replace

Chlorine is the traditional chemical disinfectant in drinking water, used since the early 20th century to inactivate or chemically kill microorganisms in our drinking water. Chlorine has a proven record of reliability in drinking water safety, which is hard to replace.


With the new disinfection byproduct rules, utilities have to balance the benefits of safety of public health through disinfection, on one hand, and the risk of byproducts of disinfection, on the other. 



Photo by Julie Black

Many small drinking water plants in the U.S. use chlorine disinfection because of its proven record.

Where Can I Find More Information?

U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water. www.epa.gov/OGWDW/mdbp.html.

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