*Back in the 1920s, trucks would carry one-ton containers to the chlorinating operations such as this one at the Ashokan Headworks in New York. (*Waterworks, *April 1927, p.131)*

Chlorination:

The Love/Hate Relationship

If left untreated, drinking water will cause waterborne diseases such as typhoid, cholera and dysentery. History books are full of stories of diseases being transmitted through drinking water. For example, the plague known as Black Death that swept through Europe and killed nearly 25 percent of the population was believed to have been transmitted by contaminated water.

However, it was not until 1854 that London physician John Snow provided proof that public water supplies could spread diseases among humans. Snow traced a cholera epidemic in London to a public well being contaminated with human wastes from a broken sewer connected to the home of someone stricken with the disease.

By the late 1800s, public health officials knew something had to be done to protect drinking water supplies. While filtration was first used in the United States around 1890, it was its combination with chlorine that provided a practical, inexpensive way to control bacteria in water.

A one-time chlorination of a contaminated well was a success in the 1850s, but it wasn't until the early 1900s that chlorination was applied on a plant basis in the United States. George A. Johnson of Hering and Fuller, a New York manufacturer of water treatment equipment, designed a full-scale chlorine installation for the Bubbly Creek Filter Plant in Chicago in 1908. This plant served the Chicago Stockyards. Johnson used chlorine through chloride of lime, dramatically reducing the bacterial content of the water after application.

In 1909, Jersey City, N.J., established the first facilities for chlorinating an urban water supply. Curiously, this chlorination plant was a successful attempt by a private water company to avoid a large expense. It was cheaper to chlorinate the water than to build sand filters or prevent contamination of the city's water source by sewage.

In 1913, Charles Wallace invented the chlorinator. It provided the first practical and effective means for the controlled feeding of chlorine gas. By 1914 most of the water supplied to U.S. cities was being chlorinated.

Advantages

Disinfection with chlorine is very popular in water and wastewater treatment (approximately 75 percent of municipal systems in the U.S. use chlorine) because of its low cost, ability to form a residual and its effectiveness at small doses.

Chlorine is a strong oxidizing agent, causing it to have a tendency to withdraw electrons from other atoms and molecules. This allows it to bond with and destroy the outer surfaces of bacteria and viruses.

Chlorine can be liquefied under pressure at room temperature, making it easy to store and transport. Chlorine also is highly soluble in water, making it easy to add to water supplies in controlled amounts. Chlorine gas reacts rapidly with water to form hypochlorous acid and hydrogen and chloride ions. In turn, hypochlorous acid reacts instantaneously and reversibly with water to form hypochlorite and hydrogen ions (Equation 1).

Chlorination is not limited to drinking water supplies. Industries use chlorine to prevent the fouling of cooling water. Food processing plants use chlorinated water to preserve the freshness of foods by killing bacteria that cause spoilage. Wastewater plants also use chlorine before they release it into rivers or other bodies of water.

Risks

In recent years, there have been concerns about chlorine. Although chlorine disinfects drinking water, it also reacts with traces of other material or particles (e.g., organic matter such as decaying trees and leaves as well as urban farm run-off) in the water and forms trace amounts of substances known as disinfection byproducts (DBPs). The most common of these are known as trihalomethanes (THMs). THMs (like chloroform) have been linked to increasing cancer risks and birth defects. The U.S. Environmental Protection Agency (EPA) has classified THMs as probable or possible carcinogens. Applying drinking water treatment methods such as coagulation/flocculation and sedimentation has reduced some of these risks.

In 1979, the EPA adopted a THM regulation limiting the allowable ingestion level of this carcinogenic disinfection byproduct in drinking water. The maximum contaminant level set for total THMs in drinking water is 0.10 mg/L. In the 1990s, the Disinfection Byproducts Rule lowered this level to 0.08 mg/L. Most municipal drinking water supplies maintain chlorine levels such that the concentrations of chloroform in the systems range from 0.02 to 0.05 mg/L. However, THMs vary with seasons and water quality.

Since 1984, American drinking water utilities have spent more than $23 million researching the production of DBPs, the risks posed by them and the methods to treat them. In addition, $150 million has been spent by the 300 largest drinking water utilities to conduct the information gathering necessary for the Information Collection Rule (ICR). The ICR is the largest study pertaining to the occurrence of DBPs and associated treatment practices.

Alternatives to the use of chlorine (e.g., chloramine, chlorine dioxide, ozone and ultraviolet [UV] irradiation) have received attention since concerns over the DBPs have emerged. Although these other processes provide efficient disinfection capabilities, each has its own disadvantages. Ozone and UV light do not provide residual disinfection or lasting protection. Also, while all disinfection alternatives do not necessarily produce THMs, they do produce some type of byproducts.

Since the attacks of September 11, there also have been security concerns regarding chlorine. Vulnerability Assessments required by the Bioterrorism Act are pointing out the risks of the use, storage and handling of various chemicals. Because of these assessments, the Fairfax County Water Authority as well as the District of Columbia Water and Sewer Authority have switched from chlorine to sodium hypochlorite.

Equation 1: Reactions of Chlorine in Water

$$Cl_2 + H_2O \longrightarrow HOCl + H^+ + Cl^-$$

$$HOCl \xrightarrow{H_2O} H^+ + OCl^-$$

Cl_2 = chlorine gas
H_2O = water
HOCl = hypochlorous acid
H^+ = hydrogen ion
Cl^- = chloride ion
OCl^- = hypochlorite ion

Future

Chlorination has improved public health greatly by eliminating or reducing the incidence of waterborne diseases. However, some organisms that cause disease are resistant to chlorine treatment. For example, chlorine disinfection is not effective for controlling protozoa such as *Cryptosporidium* and *Giardia*. Other treatments and processes are used to remove or inactivate these types of organisms. Ozone is the most commonly used disinfectant in Europe. However, this process does produce ozonation byproducts.

Since chlorination has been used for almost 100 years to disinfect water supplies, many of the DBPs from chlorination have been identified and researched. Much less is known about the kinds of DBPs produced from alternative methods.

Many utilities now are using multi-barrier approaches to disinfection. These methods are reducing DBPs while allowing utilities to continue using disinfectants like chlorine.

About the Author:
Bill Swichtenberg is the editorial director of *WEM.*