# Advances in Chemistry Improve Water Purification Processes

The time period before water purification was implemented was a time of trial to improve public health. The gradual advances in technology and public policy that occurred from the 1500's to the present show improvement in public health due primarily to improved water sanitation. Joshua Barzilay notes in his book The Water We Drink that the Roman Empire (after its downfall) had cities covered in garbage and a lack of drainage systems. This chaos promoted the spread of disease (1). Typhoid and cholera plagued the population. Cholera, an intestinal infection caused by vibrio cholera bacteria, spread through the consumption of contaminated water or food, killed thousands in Germany, England, and the US in the 19th century (1). Cholera causes dehydration and diarrhea. Similarly, during the Renaissance, extreme overcrowding caused a decline in the sanitation of cities. Barzilay notes that following the Renaissance, many people were unaware that microbes in the public water supply were the cause of disease. However, at the end of the 18th century, because of vaccinations, the number of toxic-water victims decreased. Nevertheless, Barzilay notes that there was "no overall approach to improving public health or sanitation" (1).

The nineteenth century was a time when government recognized its responsibility to "protect the welfare of its citizens" (1). There was a realization that poverty-stricken areas were at risk of disease from infected water and that it was an obligation of government to provide clean water. A filtering technique was introduced in London; water from the Thames River was filtered prior to use. However, the filter did little more than remove large particles from the water (1).

Louis Pasteur in France and Robert Koch in Germany found that water was a habitat for bacteria that functions as a "medium of transfer" for disease. Removal of bacteria could help prevent the spread of disease. Physician John Snow proved this discovery in 1854 when he linked the cholera epidemic in London with a source of water by removing the handle of the Broad Street Pump. By cutting off the water supply, cholera bacteria could not spread. With a focused approach on water sanitation and water sources, standards were created for water purification in the late 19th century.

The early nineteenth century was plagued with disease caused by contaminated water. Barzilay notes that “diarrheal disease was the third leading cause of death at the time in the United States” (1). Both the 1833 cholera epidemic in New Orleans and the typhoid epidemic in the Midwest called for quick solutions. In Lawrence, Massachusetts the first sand-based water-filtration system was introduced. After sand filtration was adopted by several water suppliers, the spread of typhoid fever decreased. According to Barzilay, 13 cities had adopted sand filtration. An added concern was how to remove large amounts of sewage and toxic wastes from reservoirs. After the introduction of chlorination in 1909 in Jersey City, New Jersey, toxic waste was removed through chlorine disinfection. Government intervention through two laws reduced the amount of waste in water. The Rivers and Harbors Act “prohibited the discharge of refuse into navigable waters” and the 1948 Federal Pollution Control Act prohibited disposal of waste into public waters and also required producers of pollution to “pre-treat their effluents to minimize water pollution” (1).

As industrialization became pronounced in the 20th century, the contamination of water became a large concern. Drinking water contaminated with chemicals produced tumors in fish, forcing the government to establish the Safe Drinking Water Act. The government could oversee surface and groundwater sources. In addition, the government created two types of regulations for water quality: mandatory and non-mandatory enforceable maximum contaminant levels. These standards focused on “immediate” and “long-term” outcomes (1). Government officials checked water for a variety of pollutants: microbiological substances, metals, inorganic chemicals, volatile and nonvolatile organic chemicals, and radionuclides. These inspections and water-purification laws enabled successful control of drinking water.

Purifying water in the most cost-effective manner was debated in the 20th century. A complete drinking-water- treatment process includes aeration, coagulation, flocculation, sedimentation, filtration, disinfection, and in some cases, fluoridation. Depending on the contaminant, a specific method can be used. For example, sedimentation and filtration are the best methods to remove pesticides (4). Sedimentation and disinfection are used to remove microbes (4).

Wastewater undergoes a two-step treatment process. The first step, called the primary treatment, settles solids, allows fats to rise, and removes large debris. The water is then sent to secondary treatment where sugars and soluble fats are consumed by natural microorganisms called "activated sludge" that live in the wastewater. The "activated sludge" removes organic contaminants. It is then sent to clarifying basins where the "activated sludge" settles out of the water. High quantities of oxygen are needed for this treatment (3).

Disinfectants are used in drinking water treatment because they are effective against bacteria. Abraham S. Behrman reports in his book Water is Everybody's Business: *The Chemistry of Water Purification,* that the three major types of disinfectants are chlorine, bromine, and iodine (2). Ozone is effective but expensive. Chlorine, a cheap gas, is fed to a chamber where it can dissolve in a small quantity of water. This chlorine-saturated water is fed continuously to the water being treated (2). Due to chlorine's ability to oxidize organic substances, it destroys matter that contaminates water with offensive odor and taste. Chlorine destroys organisms by affecting the chemical composition of enzymes that are important for the life of the organism.

Chlorine was first used to disinfect water by C.R. Darnall, a major in the US army. In 1912, chlorine was used in a plant in Niagara Falls, New York (2). Temperature, pH, time of contact and "chlorine demand" determine the required dose of chlorine. Low pH, high temperature, a low "chlorine demand", and a long time for contact are suitable for eliminating a large population of bacteria (2).

When chlorine interacts with water it forms hypochlorous acid which decomposes into monatomic oxygen and hydrochloric acid as shown in Figure 1(2). The monatomic (nascent) oxygen produced is responsible for destroying organic matter.

Bromine can also be used. Because it is a liquid at room temperature it need not be pressurized. However, the higher cost, corrosiveness, and high vapor pressure makes it a less popular disinfecting agent (2).

Ozone, another disinfectant, is a strong oxidizing agent that easily decomposes any organic matter. However, to create ozone, an electric current must be passed through a stream of oxygen. This expensive process reduces the popularity of ozone as a disinfectant (2). The ozone molecule shown in Figure 2 contains three oxygen atoms. Ozone breaks into molecular oxygen ($O_2$) and a third atom of oxygen that is a strong oxidizing agent.

$$\mathbf{H_2O + Cl_2 \rightarrow HCl + HClO}$$

$$\mathbf{HClO \rightarrow HCl + O}$$

**Figure 1.** The production of “nascent” oxygen when chlorine and water interact. From Behrman, Abraham S. *Water Is Everybody's Business; the Chemistry of Water Purification*.Garden City, N.Y.: Doubleday, 1968. Print.

$$\mathbf{O3 \rightarrow O_2 + O}$$

**Figure 2.** Ozone, a tri-atomic molecule breaks into molecular oxygen and a “nascent” oxygen atom. From Eagleton, Jim. "Ozone in Drinking Water Treatment." Environmental Protection Agency, 1 Feb. 1999. Web. 13 July 2010. <http://www.cwtozone.com/uploads/SalesDocs/Markets/Bottled%20Water:Beverages/Papers/Technical%20Papers/EPA%20ozone_drinking_water.pdf>

The changes that have occurred in water sanitation can be attributed to the development of chemistry applied to public health. The process of water purification was originally a two-step procedure that included sand sedimentation and filtration. With advances in chemistry, coagulation was introduced for a cleaner outcome. Coagulation is a process where chemicals are used to clump small particles together enabling them to settle (2). Coagulants such as aluminum hydroxide, iron hydroxide, and aluminum sulfate (most common) are formed within the turbid water rather than added to it as shown in Figure 3 (2). The coagulating chemical is formed in the water where it can enclose nearby particles. The pH of the water must range from 5.5-7.5 for the coagulant to be most effective (2). In addition, the positively charged coagulant is used to neutralize electric charges on the particles. Neutralization helps to precipitate the particles that carry a negative charge and repel each other. The turbid water is sent to a mixing tank where the coagulant chemicals are prepared and mixed with the water for 5 to 10 minutes. The water then passes through coagulating basins for hours where large particles settle out. The water is finally sent to a sand or pressure filter. A sand filter is one where the filtering medium is a layer of sand atop layers of course gravel in the open air. A pressure filter uses a closed tank, higher pressure, and small grains of sand as a filtering medium. Due to the small sand particles, low turbid water is filtered at higher pressure to increase the rate of flow. Coagulation takes place within the pressure filter itself. If further treatment is necessary, disinfectant chemicals (chlorine, bromine) are used.

$$2\ Al(OH)_3 + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3{\cdot}6H_2O$$

**Figure 3.** The preparation of liquid aluminum sulfate. When aluminum sulfate is added to turbid water, the reverse reaction takes place. The aluminum hydroxide acts as the coagulant. From *Behrman, Abraham S. Water Is Everybody's Business; the Chemistry of Water Purification. Garden City, N.Y.: Doubleday, 1968. Print.*

The extent of water treatment needed depends on the level of contamination and the source of water. According to UNICEF, 1.1 billion people lack access to “safe drinking water” (1). Water supply comes from surface and ground waters (1). Surface waters include lakes, rivers, and reservoirs while ground water comes from drilled aquifers. Communities that are not near surface waters obtain water through transport from watersheds (1). Small water suppliers use groundwater as their main source while municipal water suppliers use surface waters. The Geological Survey of Norway reported that, “groundwater is used by about 2 billion people worldwide” (8). Other sources of water come from the ocean and from rain. Desalination of ocean water is expensive and is not yet used in the United States. Areas such as the U.S. Virgin Islands and Bermuda use rainwater for water supply (1). Obtaining and filtering this water, however, can be expensive.

A.S. Berhrman notes that the cost of water purification depends on the turbidity and amount of coagulant used to remove microorganisms (2). The cost of water purification is determined by the distribution of water, maintenance, and administration that controls operations (2). Berhrman also mentions that “the operating cost at a filter plant is only part of the total cost of delivering water to the consumer. “(2). Compared to the high costs of consuming bottled water, municipal tap water is a cost-effective choice. A report from *The Emerson Electric Company*, a water-purification company, noted that the typical cost of bottled water is about $1.50 per 16 ounces and water delivery is about 30 cents (7). Bottled water and municipal water, in terms of contamination, are similar, but the cost for bottled water is higher due to the cost of plastic bottles.

Bottled water is not completely sterile. Barzilay notes that “bottled water is not above contamination” (1). Reports have shown that 25-40% of bottled water comes from tap water (4). Bottled water is much more expensive. To counter the costs, many consumers have invested in home-purification systems to improve the taste and clarity of municipal tap water. The three major homewater-treatment systems use: distillation, activated carbon, ion exchange, and reverse osmosis. In ion exchange, plastic beads called resins containing sodium chloride are used to adsorb calcium, magnesium, and other metal ions (1). Typical costs of using these treatments range from 1 to 2 pennies per 16 ounces.

Fluoride was originally added to the water treatment process to prevent tooth decay. Barzilay notes that there were masses of children who had discolored brown teeth (1). After chemical analysis of the water, scientists discovered that fluoride was the agent responsible for the discoloration. However, the children with discolored teeth had a lower rate of tooth decay and dental cavities (1). It was determined that low fluoride content in water could counteract tooth decay. Without tooth discoloration, the most favorable ratio of fluoride to water was 1 milligram per liter (1). Studies were done following World War II to determine whether the addition of fluoride would decrease cavities in large populations. Studies showed that cavities dropped by 50 to 60 percent (1). Currently, about 60 percent of the U.S. population consumes fluoridated drinking water (1).

There is more that can be done to improve the overall quality of water. One issue that concerns many in the water industry is the conservation of water. Only 3 percent of the earth's water is fresh (primarily found in glaciers or icecaps) and only about 1 percent of that is accessible (deep or shallow groundwater that can be tapped) to consumers. With such a low percentage of potential drinking water available to consumers, it is necessary to conserve water. Barzilay suggests the use of water-efficient faucets, toilets, and showerheads (1). He suggests the implementation of building codes that require water-efficient appliances. He notes that "surveying for leaks and testing meters in buildings" can reduce wasting water. He mentions improving lawn-watering methods and recycling industrial water (1).

The Environmental Protection Agency developed the Water Alliances for Voluntary Efficiency plan that focused on the reduction of water consumption in businesses but also encouraged using water efficiently. With these plans underway, the 1998 US Geological Survey noted that “water consumption had declined by 10 percent from 1980 to 1995” in agriculture and industry (1).

Preventing pollution of water can control the amount of drinkable freshwater. Barzilay comments that “the most important way to ensure future supplies of water is to prevent contamination of freshwater sources”. He remarks that “40 percent of freshwaters surveyed are still too polluted for fishing and swimming”. While there are controls for pollution in the agricultural, mining, and forestry industries, controls for factories and sewage treatment plants need to be enforced. The San Francisco Bay Region Perspective reported that, in 2008, 2 million gallons of sewage, while being transported to the treatment plant, spilled into sewers resulting in sewer overflow (5). Stronger enforcement is vital to protecting the waters surrounding treatment factories. Barzilay adds that dumping of raw sewage in the Rio Grande River by Mexican border towns impacts the sanitation of the water. Due to poor sanitation and high rates of contamination, the Arizona Department of Health Services had to issue a state-wide warning after traces of cholera bacteria were found in the shellfish from the Rio Grande (1). To counter this threat, chlorination can be used safely to disinfect waters. Many states now require regular testing of drinking-water sources (1).

Advances in chemical technology and in civil engineering have produced effective chemical disinfection and coagulant use.  These advances have made improvements in water sanitation possible. While increased governmental intervention has made water sanitation a high priority, today’s water in many (but not all) parts of the world is of good quality because of improvements in chemical technology over the past few centuries.

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