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Cholera Epidemic Stimulates Chlorine Disinfection of Water

Introduction

The cholera epidemic in the nineteenth century became the impetus for the development of one of the most commonly used disinfection techniques for water: chlorination. Social and economic factors were responsible for spreading the disease in Europe and finally, the Unites States. Migration of people led to the spread of disease across continents and made it a pandemic. The world was hit by three major cholera pandemics before chlorination was used to curb it in the late nineteenth century.

What is cholera?

Cholera is an acute intestinal infection caused by ingestion of food or water contaminated with the bacterium "vibrio cholerae". Although the disease has a short incubation period (generally 1-5 days), it can lead to intense diarrhea and dehydration. It can lead to death unless proper treatment is given promptly.

Current Cures for Cholera

- Cholera can be successfully treated by immediate replacement of the fluid and salts lost through diarrhea. Patients can be treated with oral rehydration solution, a prepackaged mixture of sugar and salts to be mixed with water, ingested in large amounts. With prompt rehydration, less than 1% of cholera patients die.

-Antibiotics, such as tetracycline (discovered in 1948) and erythromycin (discovered in 1952) can kill vibrio cholera.

-Cholera vaccine, Dukoral, is available since 2004 [7].

What is Chlorine Disinfection?

Chlorine disinfection is defined as the use of chlorine gas to disinfect wastewater and drinking water. Chlorine gas kills most bacteria, viruses, and other microorganisms that cause diseases. Today, different forms of chlorine are also used for water disinfection; these include sodium hypochlorite, calcium hypochlorite, and chloramines.

History of Cholera

First Pandemic

Origin of the disease "cholera" lies in India. Since India was under British rule in the 1800's, the disease reached Britain through the migration of affected British soldiers. Improvements in the routes of transportation and steady flow of British and Russian troops allowed cholera to reach Moscow by 1815. The Russians tried hard to prevent the disease from spreading. They ordered their troops to surround the towns where cholera appeared and shoot any diseased people who tried to enter Russia. As the disease moved westward, the Germans also massed troops at the border in the hope of suppressing the epidemic. However, military power was no match to cholera and the epidemic seized Britain by 1831.

At that time, it was believed that the disease was spread due to 'miasmas' (poisons) in the air. Lack of medical knowledge led people to believe that only an agent spread by the wind could move with such speed and defeat all efforts to stop it. By 1832, New York, one of the major business centers of the United States, had also been contaminated by cholera due to the migration of infected English men.

The vibrio cholera bacteria can only persist under warm conditions; the disease left England by end of winter (beginning of summer) of 1832 after killing more than 20,000 Britons [2].

Second Pandemic and John Snow's observation

The second pandemic struck Britain and United States in 1848. Again, many efforts were made to stop the pandemic. British troops placed ships in quarantine to prevent the pandemic from entering the country. But all their efforts were in vain.

By this time, John Snow, a British scientist, realized that cholera could not spread by air. He reasoned that if the disease was spreading through air, every person exposed to the air should be having the same response. However, while cholera struck families living in the same building, effects varied in severity. Some of them survived the attack while many didn't. This should not have been the case if they were all breathing the same air. Snow made note of other towns in Britain where a change in water supply had accompanied a change in the death toll. For example, Exeter, which had seen 345 cholera deaths in 1832, saw only 20 in 1849 after switching Exeter's water source. Hull, on the other hand, saw a six-fold increase in cases after moving the water supply from the small streams in the hills to the river flowing through the centre of the town. Because the germ theory was not widely accepted at this time, Snow was unaware of the mechanism by which the disease was transmitted, but evidence led him to believe that it was not due to breathing foul air.

John Snow interviewed more than 400 residents of Broad Street, London. He drew a map of the region around the Broad Street pump and observed that all the deaths occurred in the region surrounding the pump (See Fig1). He concluded that those who drank from the Broad Street pump in the days of the outbreak were nine times more likely to have died than those who used water from other sources. Although Snow's chemical and microscopic examination of a sample of the Broad –Street-pump water was not able to prove its danger conclusively, his studies of the pattern of the disease were convincing enough to persuade the local council to disable the well pump. The subsequent mortality rate came down. [4].

Fig.1: Original map by Dr. John Snow showing the clusters of cholera cases in the London epidemic of 1854. Each dot stands for a 'Cholera death'. The 'Cross' represents the water pump on Broad Street.
(http://upload.wikimedia.org/wikipedia/commons/c/c7/Snow-cholera-map.jpg)

Third Pandemic and Koch's Observation

The disease came back to Europe and Egypt in 1869 through the opening of the Suez Canal connecting the Mediterranean and the Red Sea. This time, the French ports were threatened. But by this time, a famous German scientist, Robert Koch, had discovered how to grow colonies of bacteria on an agar plate. Koch knew that bacteria spread through water, but could not prove it. The epidemic gave him a chance to examine the autopsies and confirm that the bacteria were spreading through water. Like Snow, Koch noticed that 17 people living in a single building sharing a common water source had died. He built a map similar to Snow's Broad-Street map. He then examined the water and observed that it contained the same comma-shaped bacteria he had discovered in the autopsies. He named these bacteria " vibrato cholera". He had discovered the cause of the epidemic but did not know how to stop the epidemic. The solution to this problem was not found until 1908.

Johnson's solution

By 1900, Chicago and New Jersey were employing engineers to rebuild the sanitation and sewage systems. In 1908, Johnson used chlorine to disinfect water rather than rebuild the sanitation system in the cities. This was the first time chlorine was used on a large scale to disinfect the immense Ashokan Reservoir near New Jersey. Before 1900, chlorine had been applied in Europe to sewage as a disinfectant.

Chlorination

The Chlorination Process

Chlorine kills pathogens such as bacteria and viruses by breaking chemical bonds. When the bacterial enzymes come in contact with chlorine, one or more of the hydrogen atoms in the molecule are replaced by chlorine. This causes the entire molecule to change shape or fall apart. When enzymes do not function properly, a cell or bacterium dies.
When chlorine is added to water, hypochloric acid forms:
$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$
Depending on pH, hypochloric acid partly dissociates to hypochlorite ions:
$Cl_2 + 2H_2O \rightarrow HOCl + H_3O^+ + Cl^-$
$HOCl + H_2O \rightarrow H_3O^+ + OCl^-$
Hypochlorus acid and hypochlorite ion both act as a disinfectant. Chlorine is in the +1 oxidation state in hypochloric acid and hypochlorus acid is highly unstable. Both readily oxidize bacteria.

Hypochlorus acid is a better disinfectant than hypochloric acid. The cell wall of a pathogenic microorganism is negatively charged. It can be penetrated by the neutral hypochloric acid, rather than by the negatively charged hypochlorite ion (see Fig2). Hypochloric acid can penetrate slime layers, cell walls and protective layers of microorganisms and effectively kill pathogens as a result. The microorganisms either die or suffer from reproductive failure [1].

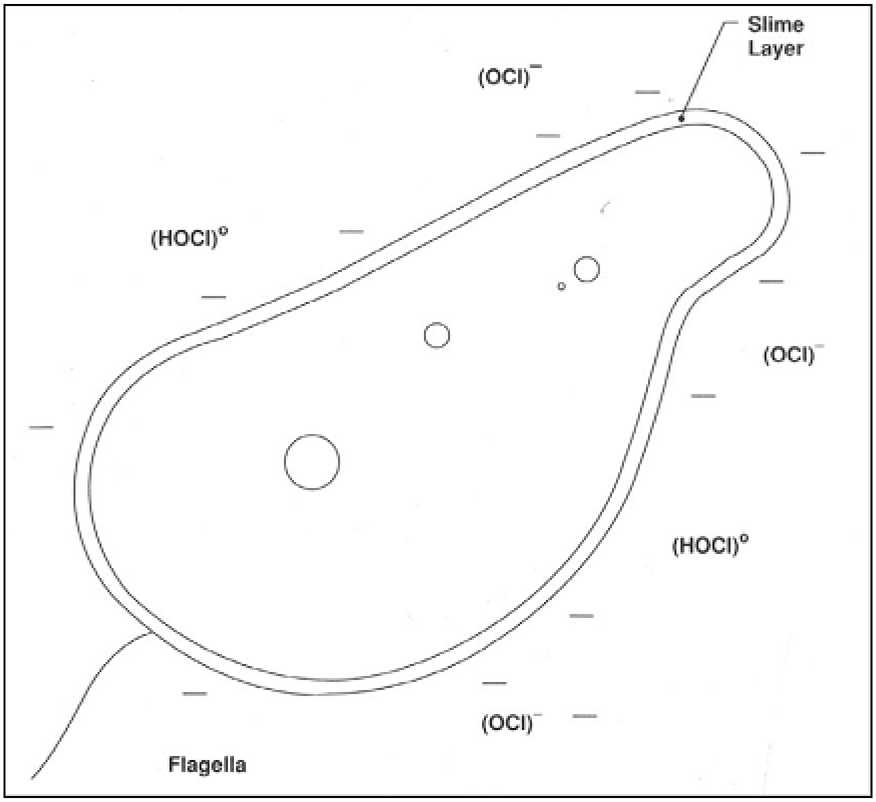

Fig.2: Neutral hypochloric acid penetrates the bacterial cell wall
(http://www.americanchemistry.com/s_acc/docs/images/Bacteria%20Pic.gif)

Success of New Chlorination Technique

The New York Times stated (1908),"So successful was this experiment that any municipal plant, no matter how large, can be made as pure as mountain spring water." In 1900, the average American had a 5 percent chance of dying of gastrointestinal infection before the age of seventy. By 1940, this rate dropped to 0.03 percent and by 1990 it had fallen to about 0.00005 percent.

The production of chlorine in the world also increased from a few thousand tons in 1910 to more than 8 million tons in 1965 (see Fig.3). More than nine tenths of the population of US uses 35 million gallons of chlorine- treated drinking water everyday[8].

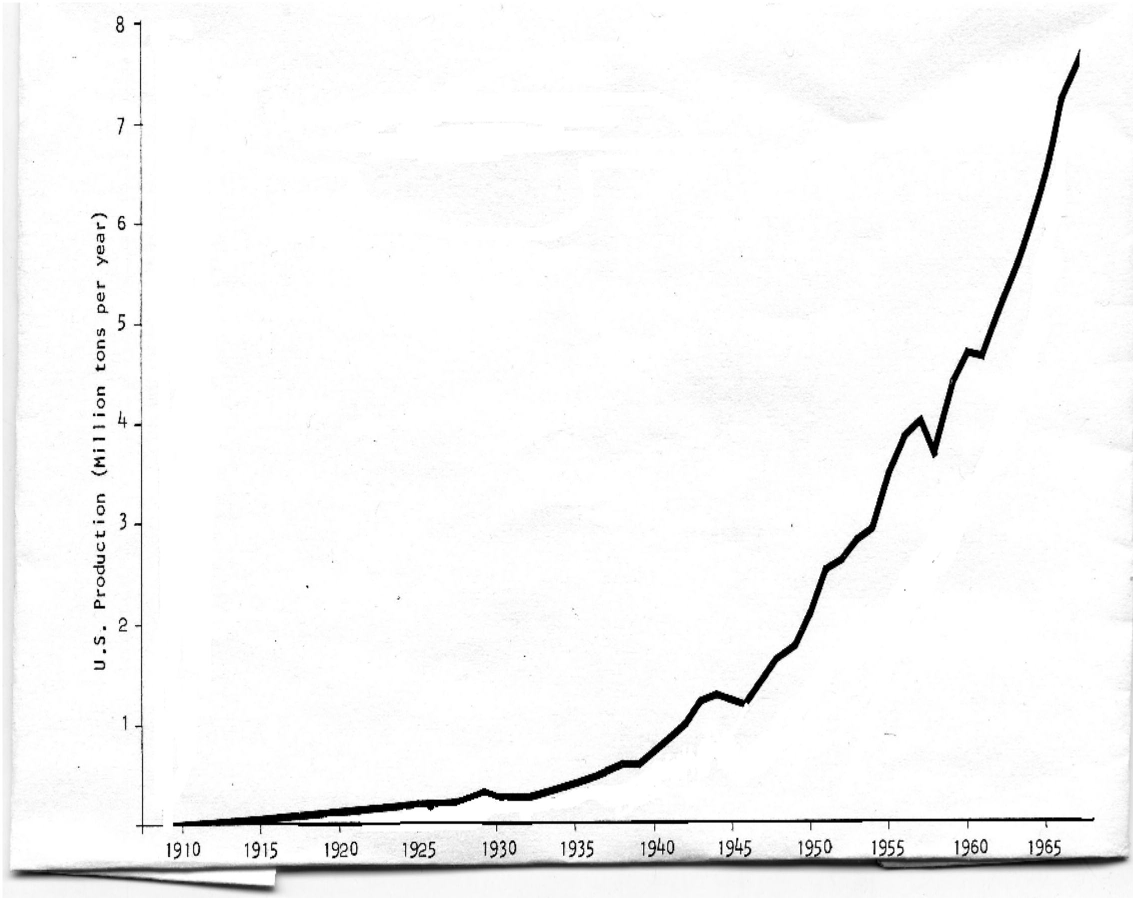

Fig.3: Increase in chlorine production in US
(Scanned from Exceeding all expectations, Chlorine Institute, pg9)

Concentration of Chlorine in Water

In the US, EPA (Environmental Protection Agency) guidelines require that tap water at any faucet should contain a minimal chlorine concentration of 0.2 ppm[6].

Cost of Chlorine Disinfection

The cost of chlorine disinfection systems depends on the manufacturer, the site, the capacity of the plant, and the characteristics of the water to be disinfected. A study conducted by the Water Environment Research Foundation in 1995 for the average dry- weather flow of 1 million gallons per day showed an estimated O&M (Operation and Management) cost of **$49,300 per year**. (A chlorine dose of 5 to 20 mg/L was used from a 1-ton gas cylinder.) Hypochlorite compounds are more expensive than chlorine gas [7].

Other Disinfection Methods

Other than chlorine, there are numerous alternate compounds used for water disinfection such as chloramines, chlorine dioxide, ozone, and UV light. There are many considerations in choosing a disinfectant including efficiency against pathogens, compliance with federal and state regulations, safe and easy shipping, and affordability.

Table1 lists various disinfectants with their advantages and disadvantages.

Comparing Disinfectants

Disinfectant	Advantages	Limitations
Chlorine Gas	- Highly effective against most pathogens - Provides "residual" protection required for drinking water -Operationally the most reliable - Generally the most cost-effective option	- Byproduct formation (THMs, HAAs[1]) - Special operator training needed - Additional regulatory requirements (EPA's Risk Management Program) - Not effective against Cryptosporidium
Sodium hypochlorite	- Same efficacy and residual protection as chlorine gas - Fewer training requirements than chlorine gas - Fewer regulations than chlorine gas	- Limited shelf-life - Same byproducts as chlorine gas, plus bromate and chlorate - Higher chemical costs than chlorine gas - Corrosive; requires special handling
Calcium hypochlorite	- Same efficacy and residual protection as gas - Much more stable than sodium hypochlorite, allowing long-term storage - Fewer Safety Regulations	- Same byproducts as chlorine gas - Higher chemical costs than chlorine gas - Fire or explosive hazard if handled improperly
Chloramines	- Reduced formation of THMs, HAAs - More stable residual than chlorine - Excellent secondary disinfectant	- Weaker disinfectant than chlorine - Requires shipments and use of ammonia gas or compounds - Toxic for kidney dialysis patients and tropical fish
Ozone	- Produces no chlorinated THMs, Haas Fewer safety regulations - Effective against Cryptosporidium - Provides better taste and odor control than chlorination	- More complicated than chlorine or UV systems - No residual protection for drinking water - Hazardous gas requires special handling - Byproduct formation (bromate,

		brominated organics and ketones) - Generally higher cost than chlorine
UV	- No chemical generation, storage, or handling - Effective against Cryptosporidium - No known byproducts at levels of concern	- No residual protection for drinking water - Less effective in turbid water - No taste and odor control - Generally higher cost than chlorine
Chlorine dioxide	- Effective against Cryptosporidium - No formation of THMs, Haas - Provides better taste and odor control than chlorination	- Byproduct Formation (chlorite, chlorate) - Requires on-site generation equipment and handling of chemicals - Generally higher cost than chlorine
[1]Trihalomethanes (THMs), Haloacetic Acids (Haas)		

Table.1: Various disinfectants for water
(http://www.americanchemistry.com/s_chlorine/sec_content.asp)

Chlorine Gas – Still the No. 1 Choice

Despite the availability of numerous disinfectants, chlorine continues to provide the most prevalent method for disinfection worldwide, primarily because of its long-proven track record for providing safe drinking water and its relatively low price. Chlorine works by forming hypochlorite (HClO) when dissolved in water. HClO is a fast-acting oxidant with a wide biocidal effect. It is highly effective at low concentrations that do not pose a danger to human health. Because chlorination is now used worldwide, cholera (and other water-borne diseases) are now rare. The cholera story provides a striking illustration of how science and chemical technology can respond to meet a major problem in public health.

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