Chlorine Disinfection - Background

NONCOMMUNITY PUBLIC WATER SUPPLY PROGRAM

Regulatory Requirements

The Safe Drinking Water Act (SDWA) requires that all Public Water Systems (PWS) using a surface water or Groundwater Under the Direct Influence of Surface Water (GWUDI) source provide treatment for three types of pathogenic microorganisms: *Giardia*, viruses, and *Cryptosporidium*. *Giardia* and viruses may be treated in part through disinfection. Combined with filtration, the total removal and inactivation must be 3-Log (99.9%) for *Giardia* and 4-Log (99.99%) for viruses.

For surface water and GWUDI systems, the SDWA also requires that a detectable chlorine residual be maintained at all points of the distribution system.

Chlorine Chemistry

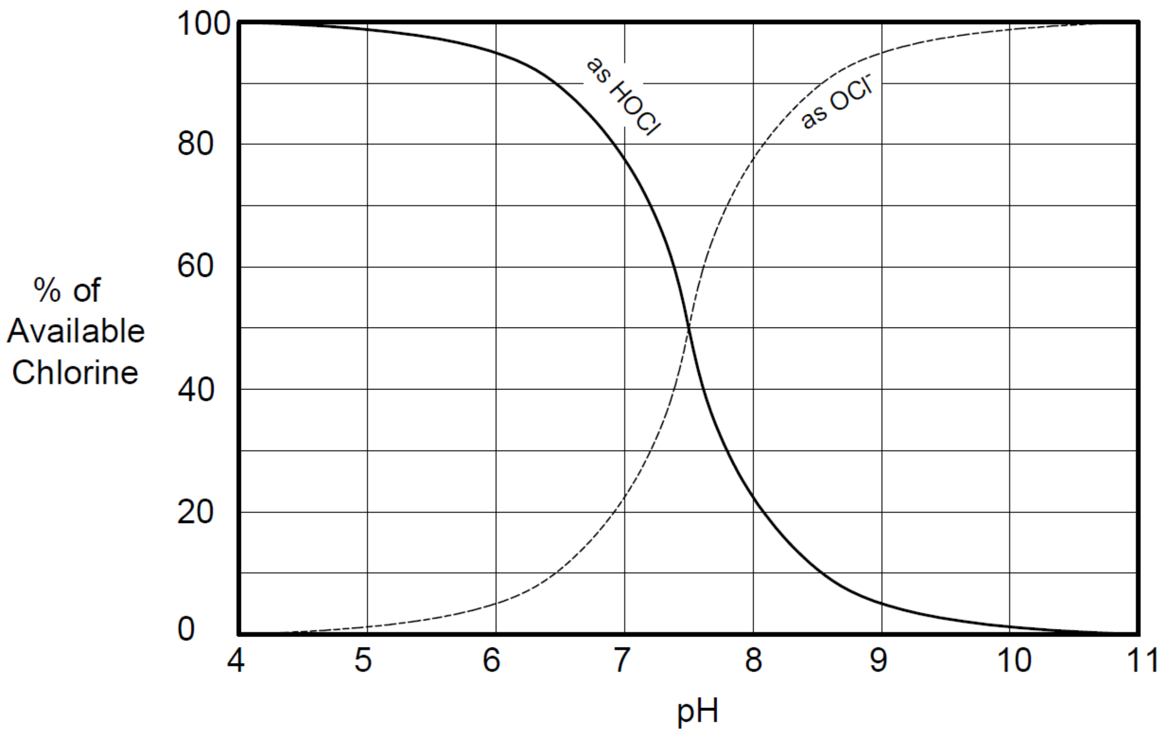
Disinfection is usually accomplished using chlorine. Chlorine can come in several forms, including liquid bleach (sodium hypochlorite), gas chlorine, and solid calcium hypochlorite. When combined with water, all of these forms of chlorine produce the same active chemicals and react with microorganisms in the same manner.

When dissolved in water, chlorine forms two related chemicals: hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). These chemicals exist in equilibrium with one another, meaning that while the total amount of HOCl and OCl^- remains constant, the amount that exists as each individual constituent can vary depending on conditions. The primary driver of this equilibrium is the acidity of the water, measured as pH. In acidic conditions (low pH), most of the chlorine will exist as HOCl, while under basic conditions (high pH), most will exist as OCl^-. Both constituents will be in equal concentration at pH 7.5. Figure 1 depicts a graphical representation of how HOCl and OCl^- ratios vary with pH. It is important to understand this concept because HOCl is a significantly more powerful disinfectant than OCl^-; if the same dosage of chlorine is applied to two different water sources of different pH, more disinfection will be achieved in the more acidic water source (lower pH).

It should be noted that using gas chlorine makes the water source slightly more acidic. Liquid and solid chlorine products have the opposite effect, making the water more basic. Liquid chlorine products also often have stabilizers added to them which can further increase the pH of the water supply.

Caution: Chlorine chemicals are harsh, corrosive, and pose potential health risks to the operator if not handled properly. Always follow all safety protocols listed on the chemical's Safety Data Sheet (SDS) and use appropriate Personal Protective Equipment (PPE). Ensure that adequate administrative and engineered controls are in place, such as ventilation, spill containment, and standard operating procedures. **Never mix liquid chlorine (bleach) with acids such as ammonia**; this will form toxic chlorine gas which can be life threatening.

Figure 1: Chlorine Speciation Varies with pH



Chlorine Reactivity and Byproducts

In pure water, chlorine will completely dissolve to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). In practical applications, however, source waters contain numerous other chemical constituents that can react with chlorine. The amount of chlorine that is used up in reactions with other chemicals in water is called chlorine demand. The dosage of chlorine must exceed the chlorine demand before a free chlorine residual (stable HOCl and OCl^-) can be achieved. Because chlorine is a strong oxidizing agent, chlorine demand is caused by constituents in the water that can be readily oxidized such as iron, manganese, ammonia, and natural organic compounds such as tannins.

Dissolved iron and manganese are oxidized quickly in the presence of chlorine and form a dark brown or black precipitate. This precipitate can then be settled or filtered out of the water supply. Groundwater sources tend to have higher concentrations of iron and manganese than surface water sources.

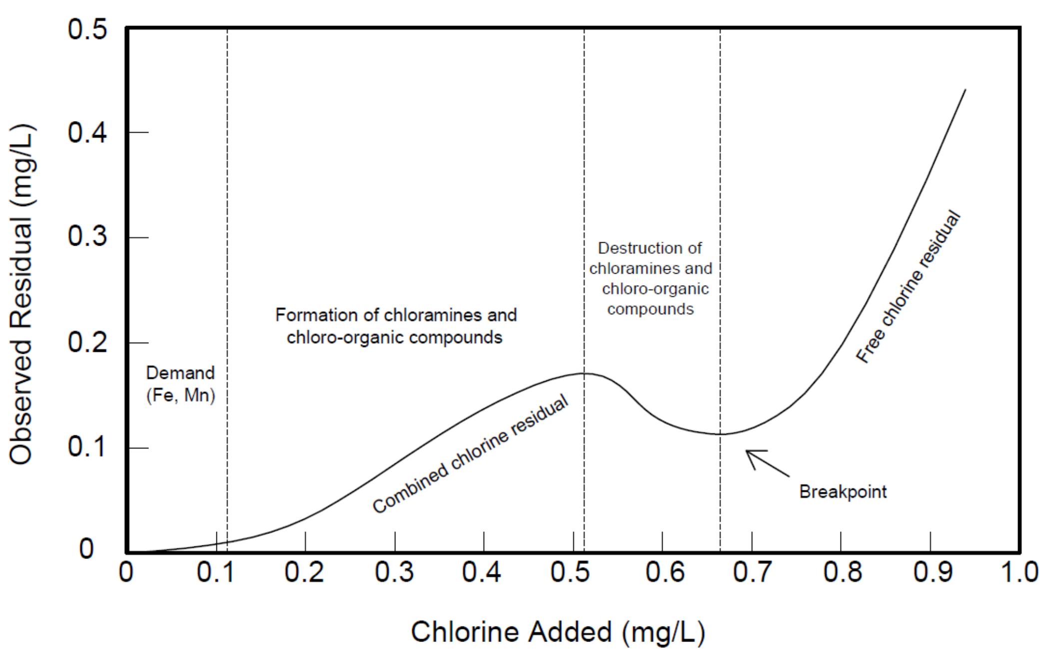
Once the iron and manganese have been oxidized, chlorine begins to react with ammonia in the water, forming chloramines. Chloramines do provide disinfecting capability, though not as much as free chlorine, and are intentionally formed in many municipal water treatment plants. They can be more stable and withstand the long residence times seen in large distribution systems when compared to free chlorine. Encouraging the formation of chloramines also minimizes the formation of other unwanted disinfection byproducts. Chloramines have a lower taste and odor threshold than free chlorine and are often responsible for complaints related to chlorine taste or scent. The sum of all chloramines and free chlorine residuals in a water supply is known as the total chlorine residual.

If more chlorine is dosed after chloramines have formed, the chloramines will eventually be destroyed, and any additional chlorine dosed will dissolve to form a free chlorine residual. The point at which this occurs is called the breakpoint. If the goal of the water treatment plant is to maintain a free chlorine residual, the breakpoint must first be exceeded. Figure 2 depicts a theoretical breakpoint curve, showing how the observed chlorine residual varies as chlorine dose is increased.

Even after the breakpoint has been exceeded, chlorine will continue to react slowly with organic constituents in the water, forming disinfection byproducts (DBPs).

These reactions are not only an operational nuisance, since old water will lose its free chlorine residual over time as a result, but they can also pose a chronic health hazard. Several DBPs have been shown to increase the risk of cancer or damage the liver or nervous system. DBPs are regulated at community water systems (cities) and nontransient noncommunity water systems (schools and large workplaces), but they are not regulated at transient noncommunity water systems (churches, restaurants, campgrounds). DBP formation can be minimized by maintaining a low chlorine residual, minimizing water age in the distribution system, or by removing organic compounds from the water prior to dosing chlorine. DBPs can be removed using certain point of use treatment devices, such as a reverse osmosis or carbon filter at a kitchen sink.

Figure 2: Chlorine Reactivity and Breakpoint Curve



Contact Time and Pathogen Inactivation

The goal of applying chlorine to a water supply is to kill or inactivate certain pathogenic organisms. For this inactivation to happen, the pathogen must be exposed to a certain concentration of chlorine (C) for a certain period of contact time (T). By multiplying these two values, we get the CT value, a description of how much chlorine must be added to a water supply under specific mixing conditions to achieve the desired pathogen inactivation. The CT value that needs to be met for compliance with the Surface Water Treatment Rules will be different for every water system and will depend on water quality characteristics (temperature and pH) as well as the treatment plant characteristics (flow rate, amount of storage volume, and mixing conditions).

Chlorine disinfection is more effective at low pH values and high temperatures; therefore the required CT value may vary depending on the acidity of the source water and the time of year.

The same CT value can be achieved with various combinations of C and T. In other words, the same level of disinfection can be achieved using a low chlorine dose and long contact time or a high chlorine dose and short contact time. There is flexibility in how much chlorine needs to be dosed when there is also flexibility in the flow rate, storage volume, and mixing conditions in a treatment plant. The amount of contact time provided will increase if there is more storage volume, if the flow rate is lower, or if the water is well mixed. Pipe flow provides the best mixing conditions, but plumbing generally does not provide substantial storage volume. Mixing conditions in storage tanks can be improved by locating the inlet and outlet on opposite ends of the tank or by adding baffles that force the water to traverse through the tank in a longer pathway. Certain pressurized storage tanks are designed with contact time in mind and come pre-fabricated with internal baffles or distributors that encourage mixing.

The log-inactivation credit granted through disinfection is additive with the log-removal credit granted through filtration. For example, a system that employs chlorine disinfection and bag filtration might receive 0.5-log inactivation credit for *Giardia* from their disinfection process and 2.5-log removal credit for *Giardia* from their bag filter. Adding the two together, the system meets the requirement of 3-log removal and/or inactivation of *Giardia*.

Related Links

[Disinfection Byproducts at Transient Systems (PDF) (https://www.health.state.mn.us/communities/environment/water/docs/ncom/disinfectbyprod.pdf)](https://www.health.state.mn.us/communities/environment/water/docs/ncom/disinfectbyprod.pdf)

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