Household Chlorination

After reading this you should know the:

- **Factors affecting chlorine demand.**
- **Importance of maintaining a chlorine residual.**
- **Factors affecting chlorine dosage requirements.**
- **Importance of safe storage of treated water.**

The World Health Organization (WHO, 2008) lists diarrheal disease as the second leading cause of death in children worldwide. Chlorination has been shown to be an effective means of destroying bacteria, viruses, and protozoa in drinking water. Much of the world's population collects and stores untreated water in the home for drinking and other uses. A means of disinfecting water in the household is therefore imperative. Availability, relatively low costs and ease of use makes disinfection with chlorine particularly attractive.

Introduction

Household or point-of-use chlorination refers to disinfection with chlorine that takes place at the location of consumption. This is in contrast to disinfection that occurs prior to distribution. Household chlorination usually serves only a few individuals per treatment. This point-of-use approach can be part of a long-term strategy or be temporarily implemented in emergency settings. Successful disinfection involves both the initial destruction of pathogens present in a given volume of water and an adequate amount of residual chlorine to prevent recontamination. These two components are commonly referred to as primary and secondary disinfection. The ability to defend against subsequent contamination is an advantage chlorine has over other disinfection means.

Fundamentals

Chlorine is an oxidant and destroys microorganisms by disrupting cell structure and function. Chlorine is available in gas, liquid, and solid form. Chlorine gas is highly reactive and toxic and must be handled with great care. Chlorine gas is therefore not suitable for household use. Two of the most widely available forms of chlorine for household disinfection are sodium hypochlorite (NaOCl) and calcium hypochlorite ($Ca(OCl)_2$). NaOCl is the liquid commonly referred to as bleach, while $Ca(OCl)_2$ comes in solid tablet form. In water, both chemicals dissociate to form Na^+ or Ca^{2+} ions and the hypochlorite ion (OCl^-) as shown in reactions 1 and 2 respectively.

$$NaOCl \leftrightarrow Na^+ + OCl^- \qquad (1)$$

$$Ca(OCl)_2 \leftrightarrow Ca^{2+} + OCl^- \qquad (2)$$

The reaction below (reaction 3) shows how the hypochlorite ion will behave in water.

$$HOCl \leftrightarrow H^{+} + OCl^{-} \quad (3)$$

The species of chlorine present is highly dependent upon pH. The equilibrium constant for HOCl is $10^{-7.5}$. Thus, pH values less than 7.5 favor the formation of hypochlorous acid. This is desirable as hypochlorous acid is a more effective disinfectant than the hypochlorite ion. The equilibrium relationship for hypochlorous acid is shown below:

10−7.5= −[+][ ]

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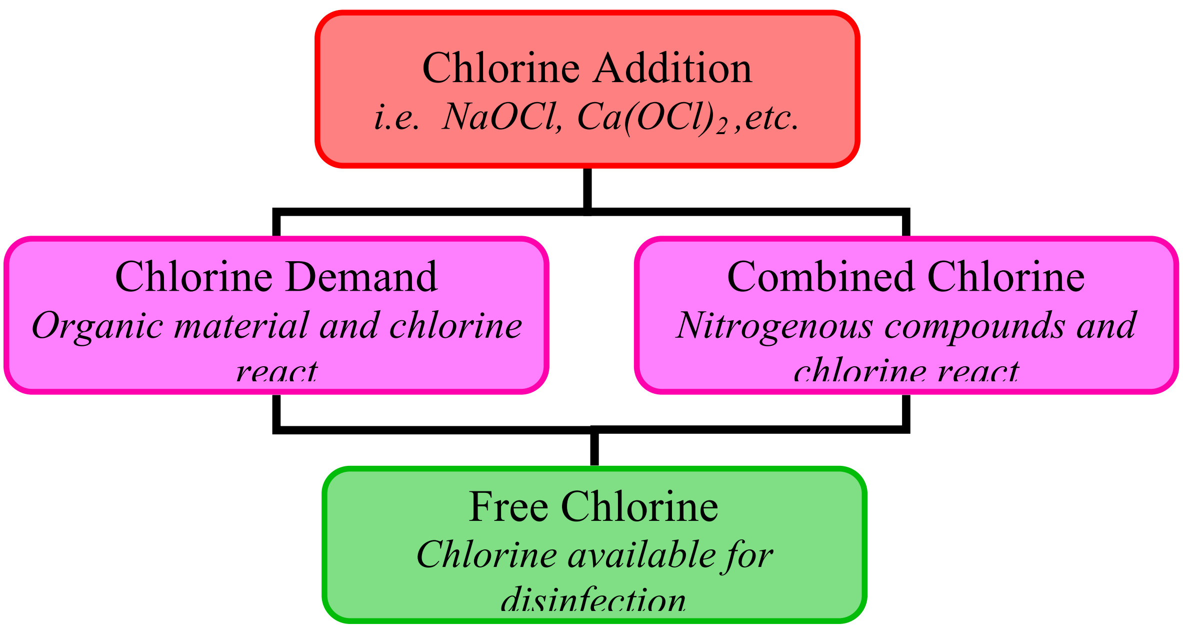
Chlorine will react with suspended and dissolved substances, in addition to pathogens. This is referred to as chlorine demand. Chlorine also reacts with compounds containing nitrogen, such as nitrate (NO_3^-), to form chloramines. The chlorine present in the form of chloramines is referred to as combined chlorine. Remaining chlorine in the form of HOCl or OCl^- is known as free chlorine.



Bacteria, viruses, and protozoa are only killed by free chlorine. Chlorine demand should be minimized to ensure sufficient free chlorine for pathogen destruction.

Residual Chlorine

Chlorine residual refers to the amount of free chlorine remaining after the initial destruction of microbial matter. Maintaining sufficient chlorine residual helps prevent recontamination of disinfected water. The CDC recommends maintaining a chlorine residual of less than $2.0 mgl^{-1}$ for 1 hour after addition of sodium hypochlorite and greater than $0.2\ mgl^{-1}$ 24 hours after addition (Lantagne, 2008).

Disinfection Byproducts

Disinfection Byproducts (DBPs) are formed when chlorine reacts with dissolved or suspended organic matter. These compounds are suspected carcinogens. It is noted that the risks associated with DBPs are significantly lower than those from microbial contamination (WHO, 1998). Thus, concerns over DBP formation should not detract from disinfection efforts. Filtering or other means of removing organic matter can be employed prior to chlorine addition to minimize DBP formation. In addition, removal of organic matter will reduce chlorine demand.

Cryptosporidium

Although chlorine disinfection is highly effective in destroying most bacteria, viruses, and protozoa, some organisms are resistant to chlorine. Cryptosporidium is one such organism and will often remain viable in water that has received only chlorine addition. The primary mode of infection by Cryptosporidium is through the ingestion of Cryptosporidium oocysts. These oocysts are relatively large, on the order of four to six micrometers. If an area is known to be prone to infection with Cryptosporidium, water should be filtered prior to consumption to remove oocysts.

Cost

Chlorine solutions can be either purchased from a commercial source or produced in the community. The later is accomplished through electrolysis of a salt such as sodium chloride (NaCl). A single generator can serve thousands of households used. Cost of chlorine from local generation varies depending on the energy used and the price of salt (Mintz, 1995). Although costs of various chlorine solutions vary, it is estimated that more than one thousand liters (1000 L) of water can be treated with liquid bleach for about one US dollar ($1.00). The cost for treatment with solid chlorine tablets ranges from one to ten US dollars ($1.00-$10.00) per one thousand liters (1000 L) of water treated (Sobsey, 2008).

Operation and Maintenance

Chlorine Concentration

Studies in South America and Africa found disparities between actual and stated chlorine concentrations in commercially available bleach solutions (Lantagne, 2009; Peralta, 2009). The concentration of chlorine present will greatly impact the efficacy of disinfection; therefore the quality of chlorine purchased should be taken into account if possible. Bleach solutions should also be stored properly to minimize degradation. Sunlight and high temperatures increase the rate of decay of chlorine solutions, decreasing ability to disinfect.

Dosage

Dosage rates of chlorine will depend on the chlorine demand of water being treated and the concentration of chlorine present in the liquid solution or solid tablet. Chlorine demand is correlated with water turbidity. Higher turbidity indicates a greater concentration of dissolved or suspended organic matter and a higher chlorine demand. If the concentration of chlorine being used and the amount of chlorine demand of the source water remain constant, then dosage rates will most likely remain constant. Prior to implementing a disinfection program, tests should be performed to ensure the administered dose of chlorine produces a desired residual. Using the minimal effective dose will help prevent tastes and odors that are disagreeable to users and will also minimize costs.

Safe Storage of Treated Water

An additional component of successful disinfection is the proper storage of treated water. Proper storage consists of a container that is free of contaminants and fitted with a lid. The lid prevents dirt and other foreign debris from entering the container, and discourages users from putting hands or other objects in direct contact with treated water. A tap is also central to safe storage and allows users to dispense water without removing the lid and coming into contact with water inside the container. Figures 1 and 2 are two examples of proper storage containers for treated water.

Figure 1: Safe storage container from Oxfam

www.oxfam.org

Figure 2: Jerry can with tap

www.gelert.com

Storage containers can be purchased from a supplier or made individually out of available materials such as five-gallon buckets or clay pots. Use of storage containers for purposes other than the treatment and storage of water should be avoided. The proper use and maintenance of containers may require the implementation of an education program. Disinfection of drinking water is futile without safe storage.

Measuring Chlorine Residual

Measuring the chlorine residual of treated drinking water is one way to determine the efficacy of a household chlorine disinfection program. The measurement of residual chlorine is a tool to gauge how well users are treating their water. . If the measured residual is not within desired the desired range, the risk of infection from drinking water is increased. There are several ways to measure residual chlorine. All methods involve the addition of a chemical that reacts with chlorine to produce a color change. The amount of color present is directly proportional to the amount to chlorine present. The chemical N, N-diethyl-p-phenylenediamine, commonly referred to as DPD, reacts with free chlorine and turns pink. The amount of pink color can be measured with a digital meter or compared visually with a color wheel.

Further Reading

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Sobsey, M., Stauber, C., Casanova, L., Brown, J., & Elliot, M. (2008). Point of use household drinking water filtration: A practical effective solution for providing sustained access to safe drinking water in the developing world. *Environment Science and Technology, 3*(2),

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Disclaimer

This document was prepared for one of the following two classes at the University of South Florida (Tampa): CGN6933 "Sustainable Development Engineering: Water, Sanitation, Indoor Air, Health" and PHC6301 "Water Pollution and Treatment". Please contact the instructor, James R. Mihelcic (Department of Civil & Environmental Engineering) for further information (jm41(at)eng.usf.edu. (learn more about our mission and development education and research programs at: www.cee.usf.edu/peacecorps).