Water Disinfection

A Practical Approach to Calculating Dose Values for Preharvest and Postharvest Applications

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WHY WATER DISINFECTION IS NEEDED

Clean, disinfected water is necessary to minimize the potential transmission of pathogens from water to produce, from healthy to infected produce within a lot, and from one lot to another over time. Waterborne microorganisms, including postharvest plant pathogens and agents of human illness, can be rapidly acquired and taken up on plant surfaces. Natural plant surface contours, natural openings, harvest and trimming wounds, and scuffing can be points of entry as well as safe harbor for microbes. In these protected sites, microbes are largely unaffected by common or permitted doses of postharvest water treatments, such as chlorine, chlorine dioxide, ozone, peroxide, and peroxyacetic acid. Therefore, it is essential that enough sanitizer is maintained in water to kill microbes before they attach or become internalized in produce. This is important in some preharvest water uses and in all postharvest procedures involving water, including washing, cooling, water-mediated transport (flumes), and postharvest drenching.

MINIMUM EFFECTIVE DOSES

Standards for the microbial quality of water should increase closer to harvest maturity and as produce moves from the field to final processing. However, excessive treatment, particularly hyperchlorination (use of high levels of chlorine), has several known and potential negative effects on product sensory quality, the environment, and human health. Water treatment should be managed with the goal of minimizing the effective dose of sanitizer used for microbial disinfection. Minimum effective doses are typically represented as the product of Concentration *(C)* and Time of exposure *(t)*, or *Ct.* Following the same principles, the term *disinfection hurdle* (D_h) can be used to help guide water quality management. The disinfection hurdle is the minimum point at which there is enough free active disinfectant available to neutralize microbial activity to an acceptable level.

CHLORINE AND HYPOCHLORITE (BLEACH) TREATMENT

Ease of use and relative low cost make hypochlorite (usually liquid sodium hypochlorite) a very common water disinfectant in the produce industry. The antimicrobial activity of chlorine compounds depends largely on the amount of hypochlorous acid (HOCl) present in the water after the treatment is applied. This, in turn, depends on the pH of the water, the amount of organic material in the water, and, to a more limited extent, the temperature of the water. Above pH 7.5, very little (<50%) chlorine can exist as active HOCl while most becomes inactive hypochlorite (OCl^-). With very long contact time, OCl^- does have some antimicrobial activity but would not be expected to result in beneficial control in typical postharvest handling systems. Below pH 6.0, noxious chlorine gas (Cl_2) is formed and does not serve as an effective water disinfectant. Of the many possible forms of chlorine, HOCl is the most readily transferred across a microbial cell wall to begin the killing process. Thus, in the management of chlorine, it is important to maximize HOCl concentrations and minimize all other forms of chlorine. It is highly desirable to keep the pH of the water between 6.0 and 7.5 to ensure adequate HOCl activity without the formation of chlorine gas, which can lead to health problems for workers and more corrosion on equipment.

The amount of HOCl needed to maintain the most active antimicrobial action depends on several dynamic factors. Chlorine is very reactive, combining with almost any oxidizable material to form secondary compounds. The amount of chlorine needed for disinfection of water depends not only on the pH but also on the amounts and kinds of inorganic (particularly ammonia, nitrites, iron, and manganese) and organic (particularly amino acids and simple proteins) substances present in the water. Because chlorine is rapidly used up by organic and inorganic molecules in wash water, a minimum level of total chlorine, the *chlorine demand,* (generally influenced by soil, plant "trash," and exudates from cut surfaces) must first be satisfied in the water

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before sufficient amounts of *free available chlorine* can kill microorganisms. The treatment times of fruits and vegetables are usually very short. To minimize the potential for excessive chlorination at peak chlorine demand, it is important to periodically replace or filter the water and blend it with potable water.

CALCULATING REQUIRED HOCl ADDITIONS

In clean water, very low levels of HOCl kill most bacteria and some viruses. Approximately 1 minute with 1 to 2 parts per million HOCl should be sufficient contact time. As water quality decreases and complexity increases, contact time or concentration must increase to maintain adequate microbial kill. Because contact times during postharvest handling are usually determined by product flow requirements, it is the concentration of the added disinfectant that is adjusted. Effective concentrations of HOCl (or other forms of chlorine) should ideally be determined by microbial testing within each system. Water quality management is often perceived as a time-consuming and costly activity; however, it is strongly recommended that it receive a high level of attention.

As a starting point, the calculations below can be made to determine the minimum concentration of free available chlorine as HOCl in wash or cooling water that is needed to kill free-floating pathogenic bacteria and viruses. The calculations are based on an adaptation of tables that were developed to achieve potable water quality standards in treated water. Higher levels of HOCl or other treatments are needed for *Bacillus* or *Clostridium* spores and for parasites like *Giardia* and *Cryptosporidium*.

Use table 1 to calculate the target measured concentration of HOCl and match it with the contact time of the system to establish the effective dose.

Example

Based on the contact time of the system, calculate the HOCl concentration necessary for an effective dose. For washing and cooling, the system has a 5-minute residence time *(t)*, and the water has a pH that is constant around 7.5 to 7.8 without adjustment when product is running through the system. The water temperature is maintained at 34° to 38°F (1.1° to 3.3°C). The table shows that the disinfection hurdle, D_h, is 20. Using these known values in the following equation, solve for C, the minimum HOCl concentration.

$$\boxed{C = D_h \div t \quad \text{or} \quad 20 \div 5 = 4 \text{ mg /L (4 ppm)}}$$

Using this result, free available chlorine can be measured using a titration kit or colorimeter specific for free available chlorine. At pH 7.8 and 34° to 38°F (1.1° to 3.3°C), only 50 percent of the measured free available chlorine, by the commonly used methods, is in the desired HOCl form. Therefore, a minimum reading of 8 parts per million is needed to hit the targeted disinfection hurdle.

> Remember, the calculated amount may be very different from the actual dose of total hypochlorite solution added to the system at peak demand. The target D_h is determined by the sensitivity of the most resistant microbe being managed. (Erwinia soft rot bacteria and *E. coli* are relatively sensitive, Geotrichum sour rot and *Rhizopus* are much more resistant.) Microbe sensitivity must be determined by direct testing because sensitivity charts calibrated to this system of calculating effective doses are not yet available.

It is easy to see the impact of water pH on C. In the same example, adding citric acid to maintain pH 7.0, C = 2.75 parts per million (HOCl is 87% of free chlorine at pH 7.0). It is common for pH to increase to 8.5 during hypochlorite treatment, resulting in C = 41 parts per million (HOCl is 17.5% of free chlorine at pH 8.5).

It is important to remember that test kits for measuring free available chlorine are only suitable for concentrations of up to 4 parts per million. It is necessary to dilute any treated water with distilled water to bring it into a measurable range and then to multiply the result by the dilution factor. Typical dilutions are 1:10 although a dilution of 1:100 may be necessary where concentrations of disinfectant are high due to the increased importance of controlling fungal spores. Always follow the instructions provided by the test kit supplier.

It is easiest to adjust and standardize water pH to 6.5 to 7.0, causing the majority of free available chlorine to convert to the HOCl form. Consulting a second table of pH and temperature then becomes unnecessary. Measurements of HOCl in water may also be adequately determined by using a calibrated ORP (oxidation reduction potential) sensor. As in the first example, 4 to 6 parts per million HOCl typically gives a sensor reading of 725 to 750 millivolts.

Table 1. Guidelines for meeting the disinfection hurdle in postharvest water treatment*

	Value of D_h in $C \times t = D_h$	
Water pH range	**32° to 41°F**	**50°F**
7.0–7.5	12	8
7.5–8.0	20	15
8.0–8.5	30	20
8.5–9.0	35	22

*Values given are the product of concentration of HOCl and time of exposure of a diversity of microbes in water to achieve greater than 99 percent kill. The value *t* is determined by the specific process or operation and assumes adequate mixing to accomplish uniform exposure.

Source: Modified from White 1992 and reflect results from laboratory and field research data.

Table 2. Current projected value of D_h in postharvest water at pH 7.0

Target microorganism	32° to 41°F	Typical contact time (minutes)
Non-spore-forming bacteria	3–6	1–5
Many viruses	3–10	1–5
Many yeasts	75–100	10–30
Spore-forming bacteria	150–250	15–60
Fungal spores	150–500	15–60
Parasite spores		
Giardia	30–100	5–10
Cryptosporidium	highly tolerant	use UV or ozone

Source: Modified from White 1992 and reflect results from laboratory and field research data.

GLOSSARY OF TECHNICAL TERMS

Antimicrobial activity. The effectiveness of a sanitizer or disinfectant in killing microorganisms.

Corrosive. The capacity of an element to weaken or eat away at equipment, especially metal.

Disinfection. The act of adding or applying a sanitizer to kill microorganisms that cause decay in produce or illness in humans.

Disinfection hurdle. A descriptive concept term that symbolizes the minimum effective exposure to achieve microbial kill. Disinfection is one of several hurdles in a prevention, reduction, and contamination control program. The disinfection hurdle is different for different types and classes of microorganisms.

Pathogens. Microorganisms such as bacteria, fungi, parasites, and viruses that can cause disease in humans or plants.

Peak chlorine demand. The maximum amount of chlorine in a batch of water that is occupied, or "used up," by inorganic and organic material. After the peak chlorine demand is known, it can be better established how much more chlorine or more clean water should be added to maintain the target disinfection hurdle. Additional steps, such as minimizing adhering soil, prewashing, or filtration may be necessary to reduce the peak chlorine demand.

Potable water. Water that is clean enough to be considered drinkable.

Product sensory. Characteristics of a product, in this case fresh produce, related to smell, taste, appearance, and texture.

Reactive. A chemical that is especially reactive is one that does not stay in one form for very long. In the case of water disinfection, it is important that chlorine stay in a particular form (HOCl) in order to be effective, making the reactivity of chlorine of particular interest.

Sanitizer. A chemical that is added or applied, in this case to water, in order to kill pathogens. A surface or water can be sanitized and free of pathogens, but sanitizing does not make the material or the water sterile.

Sensitivity. The sensitivity of a system or test refers to the lowest concentration that the system or test can detect or respond to. For example, if a chlorine test can only detect concentrations of chlorine at or higher than 1 ppm, the system's sensitivity is said to be at 1 ppm.

ADDITIONAL INFORMATION

Below are some of the many articles, research papers, and reviews available about this broad topic.

Suslow, T. 1997. Postharvest chlorination: Basic properties and key points for effective sanitation. Oakland: University of California Division of Agriculture and Natural Resources, Publication 8003. http://anrcatalog.ucdavis.edu

Suslow, T. 1998. Introduction to ORP as the standard of postharvest water disinfection monitoring. http://vric.ucdavis.edu (Go to Vegetable Information and click on Topics: Food Safety.)

Suslow, T. 1998. Prevention of postharvest water infiltration into fresh market tomatoes: Food safety and spoilage control practices. http://vric.ucdavis.edu (Go to Vegetable Information and click on Topics: Food Safety.)

White, G. C. 1992. Handbook of chlorination and alternative disinfectants. 3d ed. New York: Van Nostrand Reinhold.

You'll also find detailed information on many aspects of postharvest technology in these titles and in other publications, slide sets, and videos from UC ANR:

Postharvest Biology of Horticultural Crops: An Overview, slide set 84 / 117

Postharvest Chlorination: Basic Properties and Key Points for Effective Distribution, publication 8003

Postharvest Technology of Horticultural Crops, 2d edition, publication 3311

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