Water Treatment for Pathogens and Algae

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Water Education Alliance for Horticulture
www.WaterEducationAlliance.org

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1. An Overview of Water Treatment Technologies

By Paul Fisher, William Argo, Ratus Fischer, Peter Konjoian, Rob Larose, Alan Miller, Gary Miller, Robert Wick, and Rick Yates.

Over the last two years many parts of the continent have experienced problems with water quantity or quality. Water is a major issue for horticulture. Drought conditions and water restrictions in the Southeast are forcing companies to adapt or go out of business. With increasing urbanization, water-management authorities are regulating supply and runoff as growers and landscapers compete with both rising consumer and commercial water demands.

Growers recognize the importance of water conservation and recycling. However, the potential spread of waterborne pathogens in irrigation water has also highlighted the need to treat and manage water quality, especially in recycled water. Choosing the best water treatment method can be confusing.

Water treatment is an area of emerging technologies and innovation, with gaps in our current knowledge. Water treatment for horticulture involves perspectives from water chemistry more common to the swimming pool and municipal treatment industries than horticulture, in addition to plant pathology, engineering, and financial analysis.

Define goals and priorities

The goal for water treatment is not to sterilize the system. This is unrealistic and undesirable because many microorganisms are beneficial or benign. The real goal is to minimize the pathogen risk from water as part of an overall sanitation program—without blowing the grower's budget.

Systems approach

A big-picture perspective is required to evaluate the overall flow of water in an operation. A water-treatment specialist can help to identify the potential points of contamination that can lead to the correct combination of technologies needed.

There is no one silver bullet when it comes to water treatment. Many technologies work. The questions that need to be answered are which are the most cost-effective, how do they interact, and how can they be used effectively?

Figure 1.1. Waterborne pathogens and algae can be an issue under moist propagation conditions, especially with recirculating irrigation systems.

Filtration

Filtration and water pre-treatment underlies all other treatment technologies. Treatments such as ultraviolet light (UV) require clear water for wavelengths to penetrate pathogen cell walls. Oxidizing materials such as chlorine will react to any organic material, whether it is peat or a pathogen cell wall, and are therefore less effective in the presence of growing media and plant debris. This series will explain treatment methods ranging from reverse osmosis that removes "almost everything," including all pathogens, to options such as screen, sand and media filters.

Figure 1.2. An example of a coarse filter in a greenhouse irrigation system. A finer filtration system would improve the efficacy of ultraviolet light and other treatment systems.

Water pH and electrical conductivity

Chemical characteristics of the water source affect most treatment technologies. For example, if the water electrical conductivity is low (i.e., less than 0.20 mS/cm), then a copper ionization would need to be engineered correctly to increase the copper electrode surface area in order to provide the desired parts per million of copper. If the water pH is above 7.0, using chlorine may require acid injection for pH control, since chlorine efficacy declines at this pH.

Technologies available

Many water treatment options are available (Table 1.1). The challenge is to decide which one is best for your setup. Specific details on each of these technologies will be provided in upcoming articles.

Some equipment, such as copper ionization, ultraviolet light and ozone, have high initial investment costs, but operating costs are low and they can treat large water volumes cost-effectively. Other injectable materials such as chlorine dioxide have low initial investment costs, but have a higher operating cost per 1,000 gallons and may be better suited for plants that require the highest-quality water.

Treatment considerations

Cost is only one consideration in choosing a water-treatment method. Technologies also vary in their mode of action. For example, copper is considered a toxin, while hydrogen dioxide is an oxidizer. Some treatments, including copper and chlorine, have a residual, downstream effect, whereas other treatments are a single-point treatment. Some materials are designed only for continual low-level treatment (e.g., copper or ozone), whereas others are also an effective shock treatment to reduce biofilm (e.g., activated peroxygen or chlorine dioxide), or are suitable for surface sanitation (e.g., quaternary ammonium products).

Systems may be combined to work synergistically. An example is the addition of activated peroxygen in conjunction with ozone and/or ultraviolet light increases the sanitizing power of all these technologies. Flexibility is needed. Increasing levels of bacteria, fungi and algae have been measured as greenhouses operate through winter into spring in response to increasing temperatures, high light levels, increased plant debris and more employee movement. Because of these seasonal variables and periodic disease events, growers may need to increase or decrease water treatment.

Water treatment choices

Water treatment is part of an overall sanitation program. A systems approach is needed to correctly engineer the flow, filtration and treatment. Every application is different. For a specific example of how one greenhouse operation decided to combine treatment technologies, visit the Water Education Alliance for Horticulture web site, www.WaterEducationAlliance.org.

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This article is the first in a twelve-part series originally published in GMPro Magazine.

Table 1.1. Treatment options for waterborne pathogens in greenhouse irrigation systems

Chemical	Active ingredient	Readily soluble	Injection method	How they work	Usual range in concentration[1]	Notes
Bromine (i.e., Agribrom)	1-Bromo-3-chloro-5,5-dimethyl-2,4-imadazolidine dione	No	Tablets or granules are placed in a container with water. The supernatant solution is injected into the irrigation water.	Oxidizing agents listed in this table interact with reactive chemical groups on organic matter. The oxidation of organic matter results in a change in the chemical structure of the organic matter, and death of the pathogen. The oxidizing agent itself is also "used up" during sanitation because the agent changes chemical form as it reacts with organic matter. Plant pathogens vary in their susceptibility to the agents listed in this table, and the required concentration of oxidizing agent therefore also varies. The material being oxidized can include pathogens, peat, and fertilizer salts. Because all organic matter in the water will absorb and deplete oxidizers. Good pre-filtration is essential.	5 to 35 ppm bromine	Because of low solubility, some time is required for the undissolved tablets or granules to replenish the bromine in the stock solution. Difficult to maintain a constant concentration of bromine over the course of the day, especially with high flow rates. Requires a special injector resistant to corrosive chemicals.
Chlorine Gas	Cl_2	Yes	Chorine gas is bubbled through the water, were it combines with the water to form hypochlorous acid (HOCl) and hydrochloric acid (HCl).		0.5 to 2 ppm free chlorine. Hypochlorite is a weak acid and can be found in solution in two different forms, OCl^- and HOCl. Because the HOCl form is much more effective at disinfecting than the OCl^- form, the water pH should be controlled, as sanitizing reactions tend to be slower at higher pH.	Hazardous gas requires special equipment, ventilation, and handling. As with all chlorine application methods, higher than recommended concentrations can be toxic to plants.
Sodium Hypochlorite	NaOCl	Yes	Liquid NaOCl solutions (5% to 15% chlorine) are injected directly into irrigation water.			Requires a special injector that is resistant to very corrosive chemicals and has a very high injection ratio. Has a limited shelf life. Warm temperatures and sunlight speed up breakdown. Never combine with fertilizers or other chemicals containing ammonium.
Calcium Hypochlorite	$Ca(OCl)_2$	Yes	Granules may be dissolved in water, or tablets can be eroded in a flow-through feeder for more automatic chlorination, at chlorine concentrations up to 10,000ppm, depending on the feeder and operating conditions.			Calcium hypochlorite solutions of up to approx. 21% can be prepared, but due to the presence of insoluble materials such as calcium carbonate solutions of above 200 ppm tend to be cloudy. Sediment forms with very concentrated solutions. At less than 100ppm available chlorine there should be no apparent cloudiness or sediment.
Chlorine dioxide (i.e., Ultra-Shield, Selectrocide)	ClO_2	Yes	Dry packet or tablets placed in water, ClO_2 solution generated in stock tank.		Injected into irrigation lines. Continuous injection of residual concentration of 0.25ppm or less. Twice a year shock treatment at 20 to 50 ppm depending on product.	Stock solution should be used within 15 days to minimize loss due to volatilization. Maximum stock concentration of 500 or 3000 ppm depending on product.
Ozone	O_3	No	An electrical arc is used to produce the ozone from bottled or atmospheric oxygen. The ozone is then bubbled through the water.		Residual effect from reaction products (peroxides, organic radicals). Breaks up biofilm. 10 grams/hr/m³.	Requires professional design based on water analysis. Proper design prevents ozone from escaping into the atmosphere in hazardous concentrations.
Activated Peroxygen (i.e., ZeroTol, SaniDate)	Hydrogen dioxide/hydrogen peroxide (H_2O_2) and Peroxyacetic acid/peracetic acid $CH_3COO\text{-}OH$	Yes	A stabilized H_2O_2 and peracetic/peroxyacetic acid solution that is injected directly into irrigation water. Peroxyacetic acid is a more effective biocide than H_2O_2 alone.		27 to 540 ppm H_2O_2	Requires a special injector that is resistant to very corrosive chemicals and has a very high injection ratio, or the material must be diluted before injection.

Table 1.1, continued. Treatment options for waterborne pathogens in greenhouse irrigation systems

Chemical	Active ingredient	Readily soluble	Injection method	How they work	Usual range in concentration[1]	Notes
Ultraviolet (UV) radiation		N/A	Water is exposed to high doses of UV light in tubular chambers. Most common are low pressure mercury vapor lamps with a wave length of 254 nm, close to the optimum range for killing pathogens.	UV radiation disrupts the genetic material in the cell, effectively killing it. Dose, exposure time and turbidity determine effectiveness.	250 mJ/cm^2 eliminates most pathogens. No residual effect on pathogens downstream of treatment.	The effectiveness of the lamp decreases with age. Any particulate matter in the water will disperse the light, making the application of UV radiation less effective. Good pre-filtration is essential. Often used with other disinfecting material to get some residual effect.
Copper ionization	Cu^{++}	Yes	An electrical charge is passed between copper bars or plates, releasing copper ions into the water.	Copper ions are a toxin to most pathogens, incl. *Pythium*, *Phytophthora*, *Xanthomonas*, and algae. Recent advances in controls produce consistent copper levels and reliable results.	0.5 to 1 ppm Cu for pathogens. 1 to 2 ppm for algae and biofilm.	Less effective if water pH is above 7.5. Choose a system which actively controls copper output according to flow and EC. Applied copper concentrations are within US drinking water standards and a fraction of plant toxicity levels.
Heat Treatment/ pasteurization		N/A	Water is heated to specific temperature, and waste heat is recovered to pre-heat incoming water.	Pathogen resistance to heat varies. Effect largely independent of water quality.	An example treatment is 203ºF for 30 sec. No residual effect on pathogens downstream of treatment.	High energy use makes it expensive for large flow. To prevent scaling of heat exchangers from hard water, pH needs to be reduced to 4.5, then raised again as needed for irrigation. Best for low flow – high sanitation applications.

Chemical names and trade names are included in this publication as a convenience to the reader. The use of brand names and any mention or listing of commercial products or services in this publication does not imply endorsement, nor discrimination against similar products or services not mentioned. Individuals who use chemicals are responsible for ensuring that the intended use complies with current regulations and conforms to the product label. Be sure to obtain current information about usage and examine a current product label before applying any chemical. For assistance, contact your state pesticide regulating authority.

Notes on water treatment options

- Desired concentration depends on the application (e.g., shock versus continuous treatment and the targeted pathogens). See product label and manufacturer's instructions for specifics.
- All treatment methods mentioned are non-specific and react with any type of organic matter, whether it is a pathogen, algae, or a particle of peat. In all cases, the cleaner the water is before the treatment, the more effective the disinfection method is at removing pathogens.
- Bromine, chlorine products, ozone, peroxyacetic acid, and hydrogen peroxide are strong oxidizing agents. Metal micronutrients (copper, iron, manganese, and zinc) are easily oxidized (particularly iron). It is likely that long-term exposure (over 20 minutes) of metal micronutrients to these oxidizing agents will decrease their solubility. Chelated micronutrients should be only slightly less affected than sulfates.
- Ultraviolet radiation is a photo-oxidizing agent. Research by Cornell University on photo-oxidation of iron in fertilizer solutions indicates that the greater the light exposure, the less iron that will remain in solution.
- Quaternary ammonium compounds such as Green-Shield®, Physan 20™, or Triathlon™ are listed for disinfection of walkways, benches, tools, and flats, but are not for use with irrigation water.
- Liquid hydrogen peroxide/hydrogen dioxide (H_2O_2) solutions (35-50% H_2O_2) are not U.S. EPA-registered for water treatment in greenhouses, and are less effective and stable compared with registered activated peroxygen products.

2. Biology of Waterborne Pathogens

By Robert Wick, Paul Fisher, and Philip Harmon.

You can have the best (and most expensive) water treatment program available, but still run into disease issues on your crop. That is because water treatment is just one part of an overall sanitation program for greenhouses. Understanding the biology of waterborne pathogens will help you use preventative management and chemical disinfestants more effectively. In this article, we explain key aspects of pathogen biology that affect water treatment, and describe areas of the greenhouse that should be considered for an overall sanitation program.

What pathogens can be present in irrigation water?

A wide range of plant pathogens are capable of spreading in greenhouse irrigation water. For example, it is likely that foliar nematodes, which are tiny aquatic worms, could be spread down-flow from plant to plant. Tobacco mosaic virus has been recovered from surface water outdoors. For the purposes of this discussion, only three genera that are prevalent in greenhouses (*Pythium*, *Phytophthora* and *Fusarium*) will be covered.

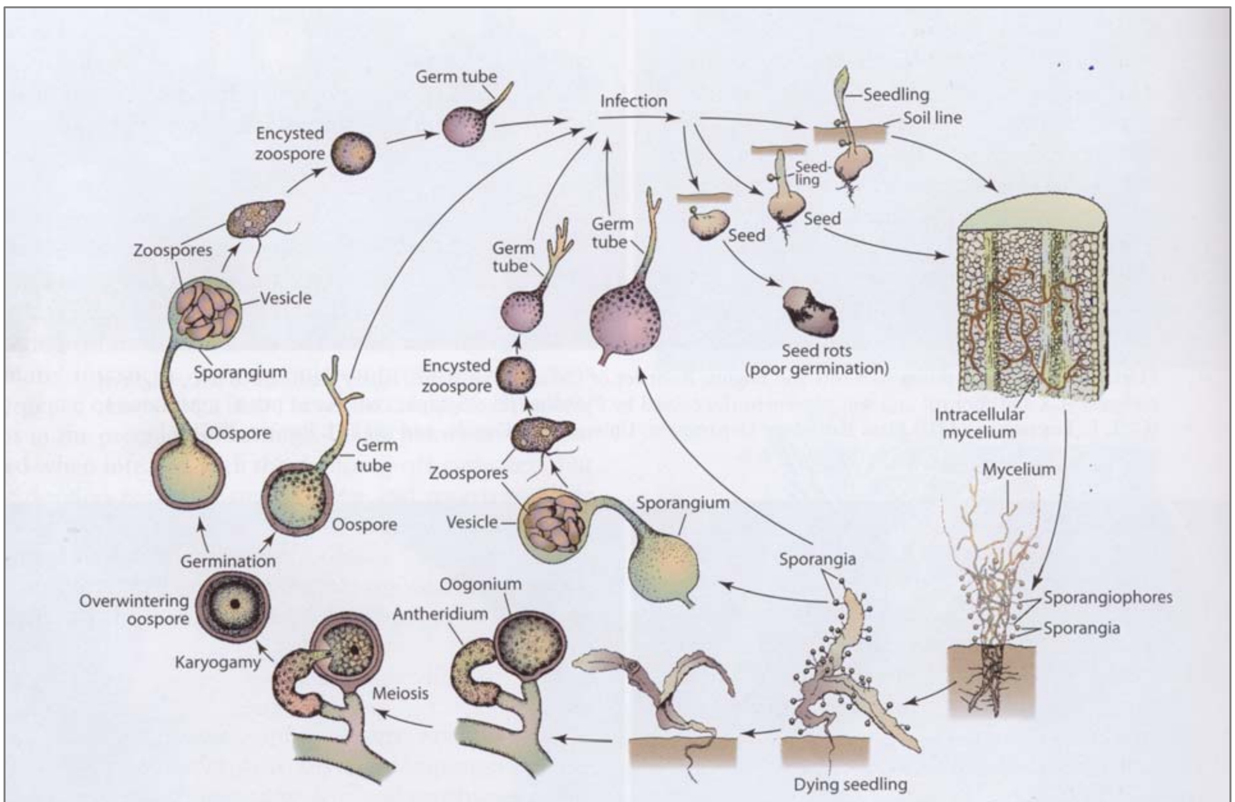

FIGURE 11-18 Disease cycle of damping-off and seed decay caused by *Pythium* sp.

Figure 2.1. A generalized life cycle of *Phytophthora*. Reprinted with permission from George Agrios, University of Florida, from Plant Pathology, 5th Edition, Academic Press.

Phytophthora (Figure 2.1) and *Pythium* (Figure 2.2) are closely related aquatic, fungal-like organisms but they are unique from each other in several ways. *Pythium* is widespread in nature, occurring in nearly all field soils whereas *Phytophthora* is only locally distributed in nature. Likewise, *Pythium* is much more common in greenhouses than *Phytophthora*. *Pythium* is a weak pathogen compared to *Phytophthora*. However, in soilless growing media and water systems, *Pythium* has little competition and can cause widespread damage to plants. In addition there are several differences in morphology, physiology and sexuality between the two organisms.

Fusarium is not an aquatic fungus but it has proven to be very successful at spreading from plant to plant in greenhouse irrigation systems resulting in significant disease problems. Fusarium wilt of hydroponically-grown basil is an excellent example. Although this particular *Fusarium* does not infect floricultural crops, there are several *Fusaria* that can. Fusarium wilt of cyclamen is a case in point.

Different life stages of pathogens

The aquatic nature of *Pythium* and *Phytophthora* make them particularly troublesome in recirculating water systems. Both require significant amounts of water to complete their lifecycle, and with few exceptions, produce swimming zoospores in large numbers. The zoospores are released into the water and are disseminated in the water stream from plant to plant where they reinfect resulting in the release of more zoospores. As the zoospores come into close proximity to the roots, the spores can find the roots through a process known as chemotaxis.

Both *Pythium* and *Phytophthora* produce structures such as oospores that allow them to survive for relatively long periods of time (years) in the absence of fresh plant material to infect. Indeed, a feeder root only 1 mm long could have 50 to 100 survival spores embedded in it. Despite their aquatic nature, these organisms can live in a dried state on concrete floors for months.

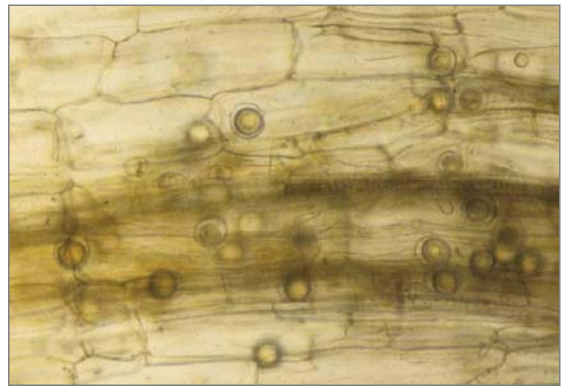

Figure 2.2. *Pythium* oospores. Photograph by Robert Wick.

Like *Pythium* and *Phytophthora*, *Fusarium* produces spores and mycelial fragments that travel in the water stream (Figure 2.3). *Fusarium* also produces special survival spores that can survive in the absence of plant material. For the same reasons mentioned above, recirculating water systems contaminated with *Fusarium* have been challenging to decontaminate.

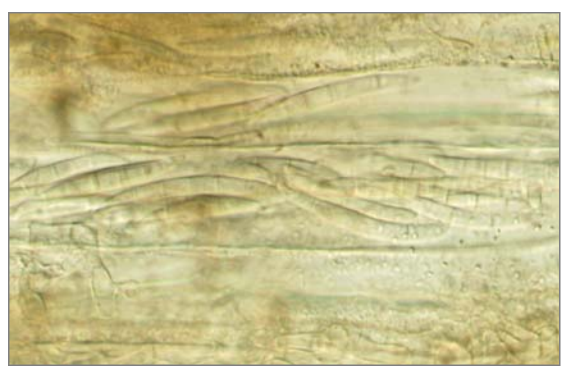

Figure 2.3. *Fusarium* spores (canoe-like structures). Photograph by Robert Wick.

Factors affecting treatment

It is important to remove plant and growing media residues and spores through filtration and regular cleaning for chemical disinfestants, ultraviolet light or other technologies to treat water.

Pathogen life stages differ in their resistance to chemical control. For example, researchers at Virginia Polytechnic University found that zoospores (the life stage that directly infect crop plants) of several *Phytophthora* and *Pythium* species were controlled at 2 ppm chlorine at discharge (sprinklers/risers). However, other fungal structures such as chlamydospores, oospores, and hyphae buried in plant and soil residues are unlikely to be controlled at that level. This is why it is difficult to provide exact guidelines on the required concentrations for chemical disinfestants.

Oxidants (for example, chlorine, activated peroxygen, and ozone) generally have a short period of effective activity. Their primary action is to cleanse the water, rather than provide long-term protection. This is especially true for point treatments, such as ultraviolet light and heat. It is possible to provide a continuous dose of oxidizing material to the system, but operating costs vary. Copper materials do not lose their activity like oxidants, but will bind to organic matter.

Duration of activity and overall efficacy of water treatment technologies decrease when high levels of organic residues are present in the irrigation water. Oxidants work by chemically changing molecules in disease-causing spores, organic residues, or fertilizers, and in the process the oxidants are used up and made ineffective. Ultraviolet light requires clear water for its light rays to penetrate spores.

All these interventions suffer from the same severe limitation: they are ineffective for treating infested organic material and mud that exists in the pots, root systems, nooks, crannies, cracks and corners of the greenhouse. For this reason, it is essential to undertake a thorough cleaning and disinfesting process between crops. Remember this basic tenet: clean surfaces first, and then disinfest (Figure 2.4). You cannot adequately disinfest dirty, soiled surfaces, nor penetrate infested organic material.

The goal is not to sterilize the greenhouse, but rather to maintain plant health. In fact, many of the microorganisms present in biofilm, soil, and water have been shown to have a benign or beneficial role, and plants may be more susceptible to pathogens when these organisms are eliminated.

A holistic approach to sanitation

The management of plant pathogens in recirculating water systems requires a holistic approach, because water is only one potential point of contamination (Table 2.1). We can begin by assuming that the water coming into the greenhouse is free of pathogens, but all bets are off if the source is local surface water.

Ideally, plant material coming into the greenhouse should also be free of plant pathogens but this is an unrealistic assumption. Nevertheless, in-coming plants should at least be visually surveyed to make sure they do not have evidence of root diseases such as random wilting, stunting or chlorosis. Use a diagnostic laboratory to identify the pathogens, and isolate sick plants to avoid disease spread. Preventive fungicides specifically targeted for root pathogens are optional but advisable if the range has a history of root diseases. There are several places in greenhouses where infected plant material can reside. The most obvious repositories are the holding tanks for the recirculating water. This is where organic material and growing media components, washed away from infected plants, come to rest. Perhaps less obvious are the corners, crevices and cracks on benches and concrete floors. Even less apparent are the corners and deadheads of pipes that recirculate the water – and the biofilm that coats the inside of the pipes. Once a system is contaminated, every effort needs to be made to eliminate the organic deposits in these areas.

Figure 2.4. Clean surfaces that harbor organic residues and pathogens first, and then disinfest. Photograph by Paul Fisher.

Conclusion

Consider water treatment as just one component in an overall sanitation program for your greenhouse. We have emphasized that removing organic residues from surfaces and water are essential before treatment. That is why filtration, the topic in the next chapter, is an important pretreatment for other technologies.

Chemical disinfestants can be phytotoxic to plants, are a potential worker safety and environmental hazard, and tend to be corrosive on equipment. Always follow label instructions and maintain equipment.

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This article is the second in a twelve-part series originally published in GMPro Magazine.

Table 2.1. Potential sources of pathogens in greenhouses

Source	Notes
Water source	Pathogen levels are usually low in unused municipal or well water. Recycled or surface water is more likely to require treatment. Test water for pathogens at both the source and at different points in the irrigation system.
Water holding tanks	Clean out residue between crops, followed by shocking with a chemical disinfestant.
Biofilm in pipes	A mix of benign, beneficial, and pathogenic or problem algae, bacteria, fungi, and other organisms which can be chemically resistant. Chemical shock is needed if water test at the hose end shows pathogens are present. Design plumbing with clean-out points for flushing out lines.
Plant and soil residue	Remove residues before cleaning surfaces. Disinfestants are not effective at sterilizing organic residues. Install coarse and fine filters for irrigation water.
Greenhouses surfaces	Clean followed by application of a labeled chemical disinfestant. Ensure there is sufficient contact time for control.
Plant material	Inspect new plant material. Regular pathogen testing is important, especially in young plant operations.
Reused containers and growing media	Compost and recycle rather than reuse. If reusing pots, ensure they are thoroughly cleaned and then disinfested.
Worker shoes, clothing, hands, and tools	Train your staff about overall sanitation. Foot baths are generally ineffective because of short contact time and high organic load. Sterilize tools between crops.

3. Water Filtration: Are You Providing Enough?

By Peter Konjoian, Ratus Fischer, Paul Fisher, and Bill Argo.

Introduction

Ask growers about the importance of a filter in their irrigation system and nearly all will agree that it's important to have one. Ask about the mesh size of the filter cartridge and half will be able to answer correctly. Lastly, ask this group to relate the mesh size of the cartridge to micron size and the percentage still standing will be down to single digits.

It is important to understand the terminology and principles of water filtration and know how to choose between filter options. Filtration underlies all other water treatment technologies because it provides a key pretreatment before chemical disinfestants can be used successfully. For example, some treatments, including ultraviolet light, require clear water for rays to penetrate water. Oxidizers such as chlorine are used up, reacting with peat or other particles if they are not filtered out of water before treatment.

Filters differ in their coarseness and role in an irrigation system (Table 3.1). Coarse filters remove duckweed, sand and peat particles to prevent clogging and abrasion of plumbing. Membrane filtration (i.e., reverse-osmosis systems) is so fine that they can actually remove disease spores from water.

Figure 3.1. Containment ponds are increasingly been required by water management authorities to capture runoff and store irrigation water.

Table 3.1. Filtration options for greenhouses and nurseries (by Ratus Fischer, fischerecoworks.com)

WHAT TO FILTER OUT		**SCREEN/MESH FILTRATION**		**MEDIA FILTRATION**			**MEMBRANE FILTRATION**			
		Coarse 4 – 50 mesh (5000 – 300 micron)	**Fine** 50+ mesh (<300 micron)	**Sand**	**Slow sand/ Bio-filter**	**Paper/ Fabric** 5–50 micron	**Micro** 1 – 0.1 micron	**Ultra** 0.1 – 0.01 micron	**Nano** 0.01 - 0.001 Micron	**Reverse Osmosis** <.001 Micron
Inorganic Particle	Debris	++	++	++ Small load only	Not intended for large amounts of solids. Excess solids will clog bio-active zone.	++	Particles other than intended for a specific membrane will shorten its life span, or destroy it. Proper pre-treatment of the water is essential.			
	Sand	+	++	++ Small load only		++				
	Silt	-	++	+ Small load only		++				
Organic particle	Debris	++	++	++ Small load only		++				
	Soil Particles	+	++ Small load only	++ Small load only		++				
	Algae, Biofilm	-	++ Small load only	++ Small load only	+ in small amounts	++	Will clog membranes.			
	Pathogens	-	-	Minor effect	++	Minor effect	+ Except viruses	++	++	++
Dissolved in-organics	Salts , Iron	-	-	-	-	-	-	-	-	++
	CaCO (Hard Water)	-	-	-	-	-	-	-	++	++
Dissolved organics	Humic acids	-	-	-	-	-	-	-	++	++
	Pesticides Herbicides	-	-	-	-	-	-	-	++	++
NOTES		Mainly pre-filtration. Drippers, nozzles need 120+ mesh	Sub-stantial dirt loads require backflush systems	Back-flush standard. Not for heavy dirt loads.	Low flow only. Pre-filtration for heavy dirt loads.	Handles heavy dirt loads in one step.	Requires lower pressure than reverse osmosis. Membranes are tailored to specific applications. Rejection rates (discharged portion of the feed water carrying concentrated waste) generally smaller than reverse osmosis.			Removes every-thing. Typically back-blended with supply water.

Dimensions: 1 micron = 10 m = 1/1000 mm = .00004 inches.
Filtration treatment efficacy: ++ indicates good, + fair, and – not effective.

Water source differences

Greenhouse operators choose from several water sources (well, surface, municipal, or reclaimed water) when building greenhouses. Less common sources include man-made containment ponds, which capture water from rain and excess irrigation. Ponds prevent runoff and groundwater contamination, and supply water during drought and emergencies.

Municipal water is usually the cleanest irrigation water source (free of sediment, organic load, chemical contamination, algae and pathogens) because municipalities filter, clean, treat, and deliver high-quality water to customers. As a result, municipal water is usually the most expensive. There's a correlation here that many growers are failing to acknowledge. The processes water is put through by municipalities to improve its quality cost money. Growers who use non-municipal water should perform some of the same filtration and treatment processes, and none of these steps are free. Simply drilling a well or tapping into a river or pond usually does not provide quality water in the absence of filtration and treatment.

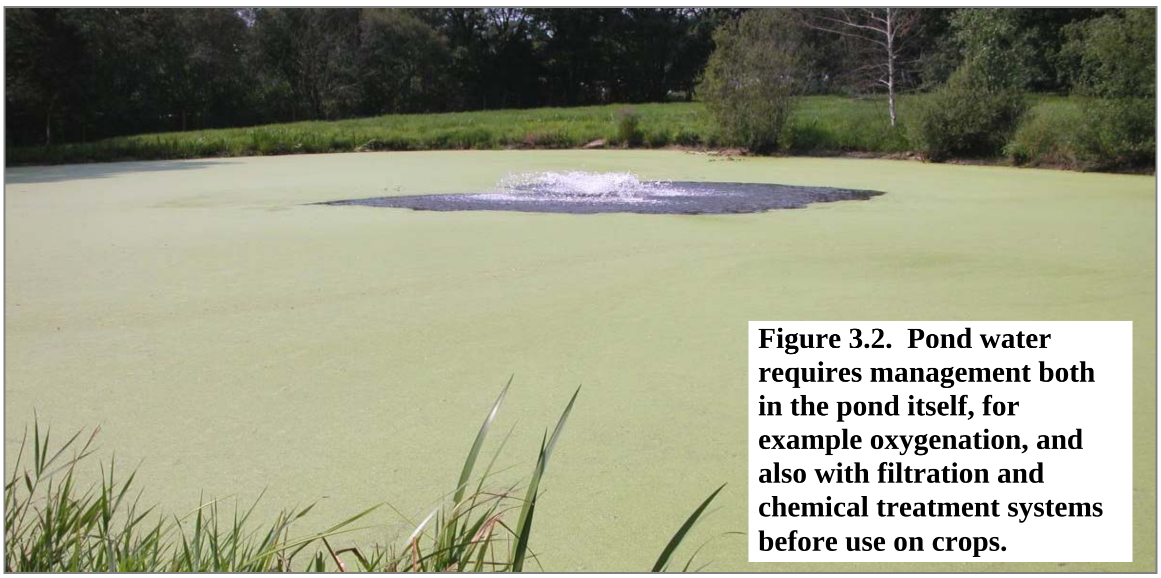

Figure 3.2. Pond water requires management both in the pond itself, for example oxygenation, and also with filtration and chemical treatment systems before use on crops.

The dirtiest water source

What are the dirtiest water sources? All water types can have their challenges. Well water and moving bodies of water such as rivers and streams are generally free of pathogens and algae, but can contain silt, especially after heavy rain. Slow-moving streams and shallow lakes may contain silt as well as pathogens and algae.

Ponds, both natural and man-made, are among the potentially dirtiest water sources for greenhouses. Small, stagnant ponds often have high levels of turbidity and microbial contamination. The presence of algae in these ponds is the rule rather than the exception because of fertilizer contamination (both nitrogen and phosphorus).

Duckweed, a common, simple plant that grows on the surface of stagnant ponds, is often confused with algae. A misconception is that duckweed presence is bad and an indicator of poor water. To the contrary, duckweed covering a pond is actually cleaning the water through bioremediation. Duckweed is actually an ally in the battle against microbial contaminants and poor water quality.

Mesh and microns

There is a relationship between mesh and micron size. Mesh sizes of 200, 300, and 400 are capable of filtering to approximately 75, 50, and 35 micron, respectively. To add perspective, an oxalis seed is 1000 microns in size, some algae are 25 micron, a *Pythium* zoospore is 15 micron, and a *Ralstonia* bacterium is only 2.5 micron (Table 3.1).

Roughly speaking, a common 200 mesh filter removes particles down to approximately 75 microns from the irrigation stream. This effectively removes sand, silt, and clay particles, and even catches some microbial complexes such as large strands of algae. This level of filtration is enough to keep sprinkler and mist nozzles and drip emitters from clogging due to solid particles in the water.

Figure 3.3. A sand filtration system in the pumphouse.

Filtration goals

You should obtain advice from an irrigation expert before installing a greenhouse-wide filtration system because one size does not fit all. A greenhouse operation using municipal water and one-directional irrigation may need only 200 mesh (75 micron) filtration to operate efficiently. A second location, using pond water that receives runoff from the operation and also uses flood floors, may need several stages of filtration to achieve better than 600-mesh (25 micron) filtration. Even at that level of filtration, *Pythium* zoospores will not be caught.

A possible multi-staged filtration system may look something like this:

- The first stage would be a coarse screen to filter duckweed and other floating debris as the water leaves the pond.
- A second stage would involve sand filtration located in the pumphouse.
- A third and final stage could be paper or belt filter that removes particles to less than 10 microns. This filter would be located in the production area to filter water as it leaves the flood area and returns to a holding tank.

Although designing filtration needs is not simple, one conclusion is very clear. With few exceptions, every greenhouse stands to benefit from additional filtration. Irrigation water can become gradually contaminated by algae and other microbial organisms over time, from the water source itself, greenhouse surfaces and biofilm present in the plumbing system.

A logical filtration goal for growers is to determine the micron level of filtration currently being achieved and simply take the next step up an imaginary filtration ladder. For instance, a grower currently using 200 mesh (75 micron) filters could consider changing to 300 mesh (50 micron). If the quality of the water source is good, this may be as easy as replacing 200-mesh cartridges with 300-mesh cartridges. If the source is relatively dirty, stepping up filtration to 300 mesh may require a second filter downstream from the first.

Figure 3.4. A paper filter ready for installation into a flood floor greenhouse.

Similarly, a greenhouse operation with flood floors and containment pond supply definitely needs a filtration system that is a well-designed, staged system, to properly filter water leaving the pond and leaving the flood floor as well. Anything short of adopting such a system will result in most chemical or other disinfestation treatments to be ineffective.

Relative cost of filtration

Filtration is relatively inexpensive when compared with the additional maintenance, plumbing equipment replacement and crop loss costs from disease that can result from inadequate water pretreatment. An effective filtration system will actually reduce the operating cost and increase the efficacy of chemical water treatments.

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This article is the third in a twelve-part series originally published in GMPro Magazine.

4. Using Sodium and Calcium Hypochlorite for Water Treatment

By Paul Fisher, Bill Argo, Chuanxue Hong, Jinsheng Huang, Austin Looper, Dean Wiegers, Rick Vetanovetz, and Youbin Zheng.

Introduction

Calcium and sodium hypochlorite are widely used to control waterborne pathogens and algae in irrigation water. You are probably most familiar with these materials as liquid bleach (sodium hypochlorite) and solid swimming pool “shock” (calcium hypochlorite). Understanding water chemistry is important so you use these materials safely and effectively.

Mode of action

Chlorine oxidizes organic matter. This includes not only the sensitive membranes, enzymes and DNA of pathogen and algae spores, but also includes peat, plant material, and micronutrient chelates carried in the water. Hypochlorite is used up during sanitizing because its chemical structure also changes, leaving calcium or sodium chloride. Filtration of non-target organic matter as a water pretreatment is important to reduce the amount of chlorine required.

“Free chlorine” is the combined concentration of hypochlorous acid and hypochlorite, along with dissolved chlorine gas. “Free residual” chlorine means the concentration of free chlorine remaining in the sample after the “chlorine demand” of the water is satisfied. Having the proper amount of free residual chlorine is important because that represents the remaining chlorine available to sanitize. Free residual chlorine decreases over time, as the free chlorine reacts with organic matter (bacteria, fungi, algae), or is broken down by sunlight.

Understanding chlorine chemistry

When sodium hypochlorite (NaOCl) or calcium hypochlorite ($Ca(OCl)_2$) react with water, the following components are formed:

- Hypochlorous acid (chlorine sanitizer, a weak acid)
- Hydroxide (a base that raises water pH)
- A calcium or sodium ion (calcium is a nutrient; sodium is not used for plant growth but slightly raises water EC).

Ca^{2+}	+	$2OCl^-$	+	$2H_2O$	<=>	Ca^{2+}	+	$2OH^-$	+	2HOCl
Calcium		hypochlorite		water		calcium		hydroxide		hypochlorous acid
Na^+	+	OCl^-	+	H_20	<=>	Na^+	+	OH^-	+	HOCl
Sodium		hypochlorite		water		sodium		hydroxide		hypochlorous acid

Relationship between chlorine and pH

Adding either sodium hypochlorite or calcium hypochlorite to water produces the hypochlorite ion (OCl^-) and hypochlorous acid (HOCl). The balance between these two chemicals is determined by the pH of water (Figure 4.1). Hypochlorous acid, which pre-dominates at solution pH below 7.5, is 20 to 30 times as effective a sanitizer as hypochlorite (favored by pH above 7.5).

Chlorine is most effective at the optimum pH range of 6-7.5. At a higher pH, more chlorine is needed for the same result. For example, if there was 1 part per million (ppm) of free chlorine (HOCl + OCl^-) at pH 7, how much free chlorine would be required to have the same effectiveness (HOCl concentration) at pH 8?

Looking at point "a" (Figure 4.1, pH 7), about 80% (0.8 ppm) is hypochlorous acid (HOCl). At point "b" (pH 8), only 30% (0.3 ppm) would be hypochlorous acid. So at pH 8, 2.7 ppm free chlorine would be needed (0.8/0.3 ppm). Nearly three times the amount of sodium hypochlorite or calcium hypochlorite would be needed at pH 8 to have the same effectiveness as 1 ppm free chlorine at pH 7.

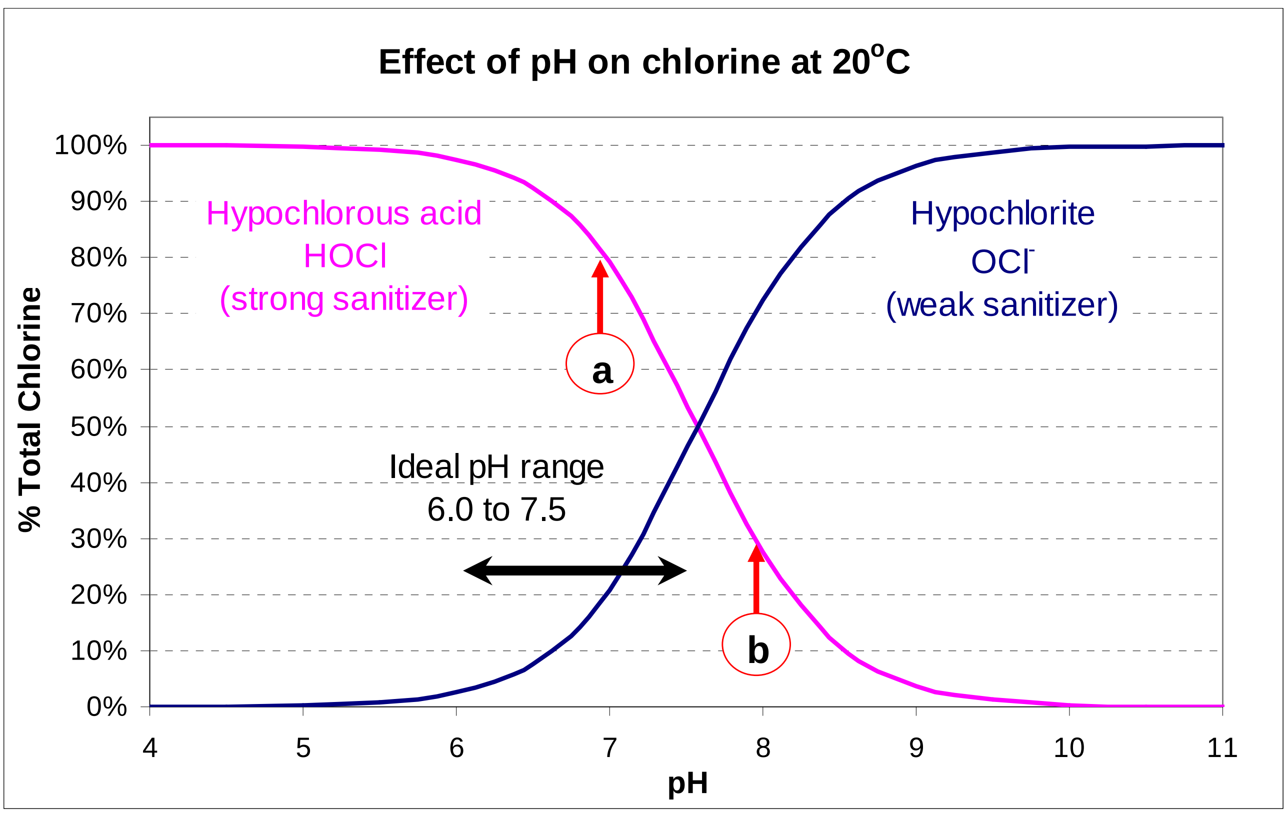

Figure 4.1. Chlorine has two main forms in water. Hypochlorous acid is a strong sanitizer, and is favored below pH 7.5. Hypochlorite predominates at high pH, and has less sanitizing power.

Increasing hypochlorite concentration will raise pH (Figure 4.2), because hypochlorite reacts with water to release a base. However, the pH response varies depending on the chemical type and supplier, and also the water quality (especially pH and alkalinity). In contrast to hypochlorite, chlorine gas and chlorine dioxide sources do not raise water pH.

Chlorine concentration is affected by organic matter

To minimize the risk that the irrigation water and plumbing systems are potential sources of *Pythium* or *Phytophthora* zoospores, 1 to 2 parts per million (ppm) residual free chlorine at the farthest emitter is required. This may require an initial injection of 5 to 6 ppm of chlorine. For example, 2 ppm of free chlorine may be added at the well source. As the water flows through the irrigation system, it has a certain contact time with biofilm and other organic matter in the pipes. Contact with water contaminants and biofilm may lead to a chlorine demand of 1.75 ppm, and in that case 0.25 ppm of free residual chlorine would remain and come out of the hose.

Once biofilm is removed and there is less chlorine demand from your irrigation system, then less chlorine may be required to achieve a residual concentration of 1 to 2 ppm. The chlorine injection rate may need to be adjusted. If the primary goal is algae control, some growers have found that a residual as low as 0.25 ppm may be adequate to ensure irrigation nozzles remain clean. The concentration for continuous water treatment is much less than that required to sanitize pots or flats, for which a 1 part bleach:9 parts water solution (approximately 5,250 ppm) for 30 minutes is recommended.

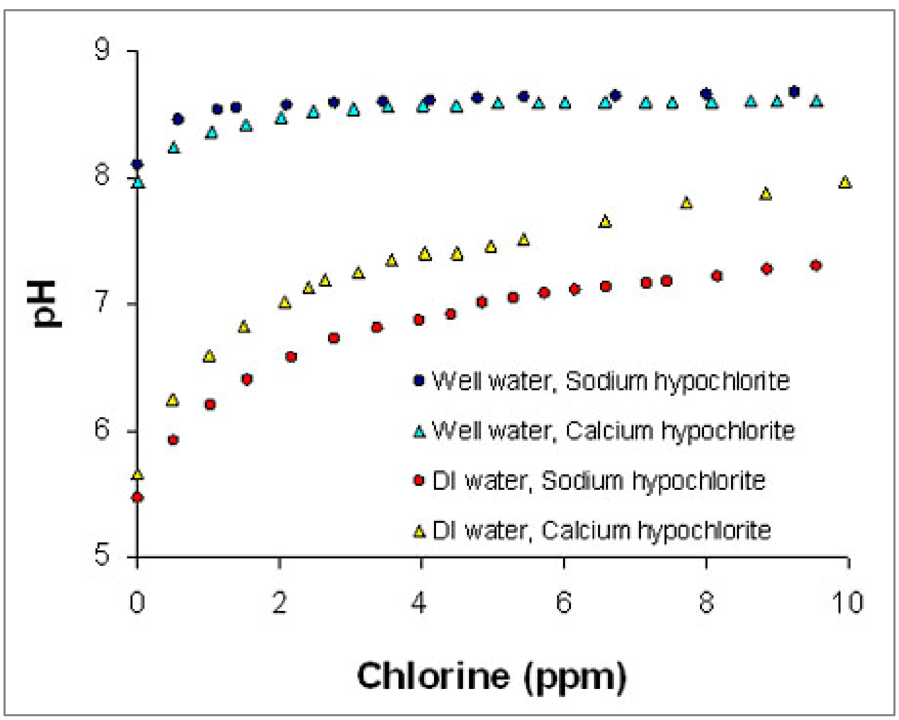

Figure 4.2. Hypochlorite is a base: increasing the concentration of sodium or calcium hypochlorite will cause the water pH to increase. In this case, deionized (pure) water or well water (112 ppm alkalinity) was used with Clorox Regular Bleach (sodium hypochlorite) or calcium hypochlorite. The exact pH-concentration relationship varies with chemical type, chemical source, and irrigation water quality. Research by University of Florida.

Effects of chlorine on pathogens

Not all life stages or species of a pathogen are equally susceptible to chlorine or other sanitizers. Virginia Polytechnic researchers found that control of mycelial fragments of *Phytophthora* required 8 ppm chlorine compared with 2 ppm for zoospores. Researchers at the University of Guelph found that 0.3 to 1 ppm free chlorine killed zoospores or sporangia of two *Phytophthora* species with a three- to six-minute contact time. Two ppm free chlorine killed zoospores of *Pythium aphanidermatum* with a contact time of three minutes. However, 14 and 12 ppm free chlorine were required to control *Fusarium oxysporum* conidia and *Rhizoctonia solani* mycelia with a 10- or six-minute contact time, respectively.

Virginia Polytechnic Institute and State University researchers found that 2 ppm free chlorine at pH 6 provided complete control of zoospores from 15 isolates of *Pythium* and 8 isolates (7 species) of *Phytophthora*. They concluded that 2 ppm free chlorine at discharge points (risers or sprinklers) will effectively control zoospores (the swimming infective stage) of *Pythium* and *Phytophthora* species in irrigation water.

Potential injury to plants

A general recommendation is to maintain chlorine levels in water at no more than 2 ppm to avoid phytotoxicity of ornamentals, but testing on your own crop mix is advised. For chlorine-sensitive crops when more than 2 ppm is required for pathogen control, the free chlorine needs to be reduced before plant contact. This can be done by dilution, filtration through an activated charcoal filter or by allowing time for the residual level to decrease.

University of Guelph research at a commercial nursery site using 2.4 ppm free chlorine to overhead irrigate plants daily for 11 weeks showed that only eight out of 22 suffered minor injury. The eight injured species were either herbaceous or broadleaf deciduous shrubs. No evergreen species were injured by chlorine.

When chlorine is added to water, calcium and sodium ions are produced. When chlorine is added on a constant basis to water, at around 1 to 2 ppm of chlorine, there is insufficient calcium or sodium to cause benefit or harm to plants from those ions. However, sodium and calcium levels may increase over time if irrigation water is recycled, requiring regular monitoring of sodium content in the water and growing medium.

It is strongly recommended to have chlorine systems professionally installed. A system that constantly monitors and can correct water pH reduces the amount of chlorine applied, increases effectiveness and improves product safety. For example, toxic gases are given off if the acidification system malfunctions and the pH falls below 4. As with all sanitizing agents, talk with experts, follow label instructions, and train your staff to ensure safe operation.

Measuring chlorine

A chlorine meter can be purchased for around $150-$300 (ExTech, Hach, and Hanna all manufacture meters, for example), or color test kits are also available. Choose a meter that measures free chlorine, rather than total chlorine (which includes forms of chlorine that are not effective for sanitation).

Another way to measure the oxidizing power of a solution is with an oxidation-reduction potential (ORP) meter, which measures in units of millivolts (mV). An ORP meter costs $100-$400. The higher the millivolts of oxidation potential, the greater the sanitizing power. An ORP reading of 650 mV of the irrigation water is a guideline for sanitation of the greenhouse environment. Although data are not available for the ORP relationship with plant pathogens, 650 mV is used by the U.S. Environmental Protection Agency as an effective level to kill food pathogens such as *E. coli*. It is important to maintain pH levels below 7.5 to ensure that the chlorine is effective at increasing ORP (Figure 4.3).

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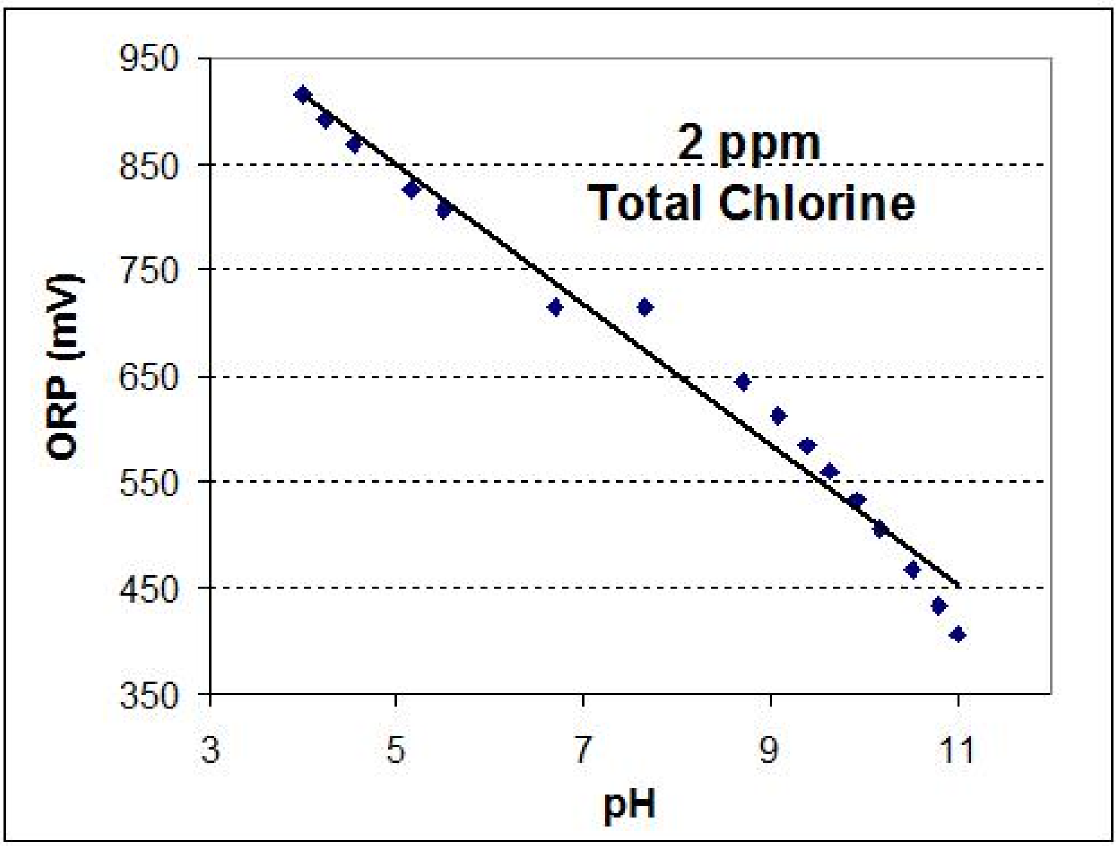

Figure 4.3. ORP, a measure of sanitizing power, increases as pH decreases. pH should be maintained in the range of 6.0 to 7.5 – at higher pH there is less sanitizing effect, and at lower pH toxic gases can be released. Research by University of Florida using deionized water and Clorox Regular Bleach.

5. Water Sanitation Using Chlorine (Calcium Hypochlorite and Sodium Hypochlorite)

By Paul Fisher, Jinsheng Huang, Austin Looper, Dave Minsk, Bill Argo, Rick Vetanovetz, and Youbin Zheng.

Chlorine is an affordable option that is the most widely-used chemical for water sanitation. Chlorine can be used to kill pathogens, bacteria that are harmful for human consumption, as well as algae and iron-forming bacteria that clog filters and nozzles. Chlorine also provides residual protection by treating water as it travels through the irrigation system and out into the greenhouse or nursery.

Forms of chlorine

There are solid (calcium hypochlorite), liquid (sodium hypochlorite), and gas forms of chlorine. All three forms deliver hypochlorous acid (HOCl), which is the sanitizing form of chlorine, upon dissolution in water. This article provides some guidelines on how to treat water with chlorine, focusing on the liquid sodium hypochlorite (i.e., bleach) and solid calcium hypochlorite (i.e., tablets) forms.

Gas Chlorine:
$Cl_2 + H_2O \rightarrow HOCl + HCl$

Sodium hypochlorite (liquid bleach):
$NaOCl + H_2O \rightarrow HOCl + Na^+ + OH^-$

Calcium hypochlorite (solid tablets):
$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca^{+2} + 2OH^-$

Dosing chlorine

Chemicals containing chlorine can simply be dosed into the irrigation water using volumetric proportion. A specific initial dose (e.g., 5 parts per million) is provided at the well head, to ensure adequate residual concentration (typically 0.5 to 2 ppm) at the outlet. The difference between the initial and residual concentration is termed "chlorine demand".

The treatment system is most effective if the irrigation water quality (chlorine demand) remains constant. If the pH, biological load, or temperature never changes then the dosing ratio can be determined using a simple chlorine meter. Simple dosing is less effective when water has a fluctuating chlorine demand, which applies to a majority of greenhouse watering systems.

Factors that increase chlorine demand include:

- Warm weather
- Use of recycled or pond water
- Accumulation of fertilizers, peat, and plant debris in the irrigation water
- Biofilm and algae

Chlorine demand

The mode of action of hypochlorous acid is through oxidation and chlorination of many types of organic material, and not just pathogens or algae. In order to make the addition of hypochlorous acid more effective for pathogen control, water needs to be pre-filtered to remove excess organic material.

Fluctuating chlorine demand of the water system affects the amount of chlorine that needs to be initially dosed to provide a consistent residual level. Research at the

University of Guelph showed that maintaining 2 ppm of free chlorine for five minutes can control most common plant pathogens. However, biological load varies with temperature and tends to increase during the spring to summer (Figure 5.1), especially with surface or recycled water sources. Higher temperatures require more chlorine injection to combat algae and pathogen growth. Seasonal fluctuations in water alkalinity or pH can also change the chlorine demand because the concentration of hypochlorous acid decreases as pH increases.

Consistent and simple chlorine dosing without adequate control of residual chlorine concentration can be harmful to plants. If chlorine demand suddenly drops (for example, because of cold weather) then residual chlorine can rise to phytotoxic levels (typically above 4 ppm hypochlorous acid for short term exposure and 2 ppm for long term exposure). If chlorine demand increases, the hypochlorous acid level may be inadequate to control pathogens. Overdosing and releasing chlorine gas into the air (off-gassing) at very low pH are also potential worker safety hazards.

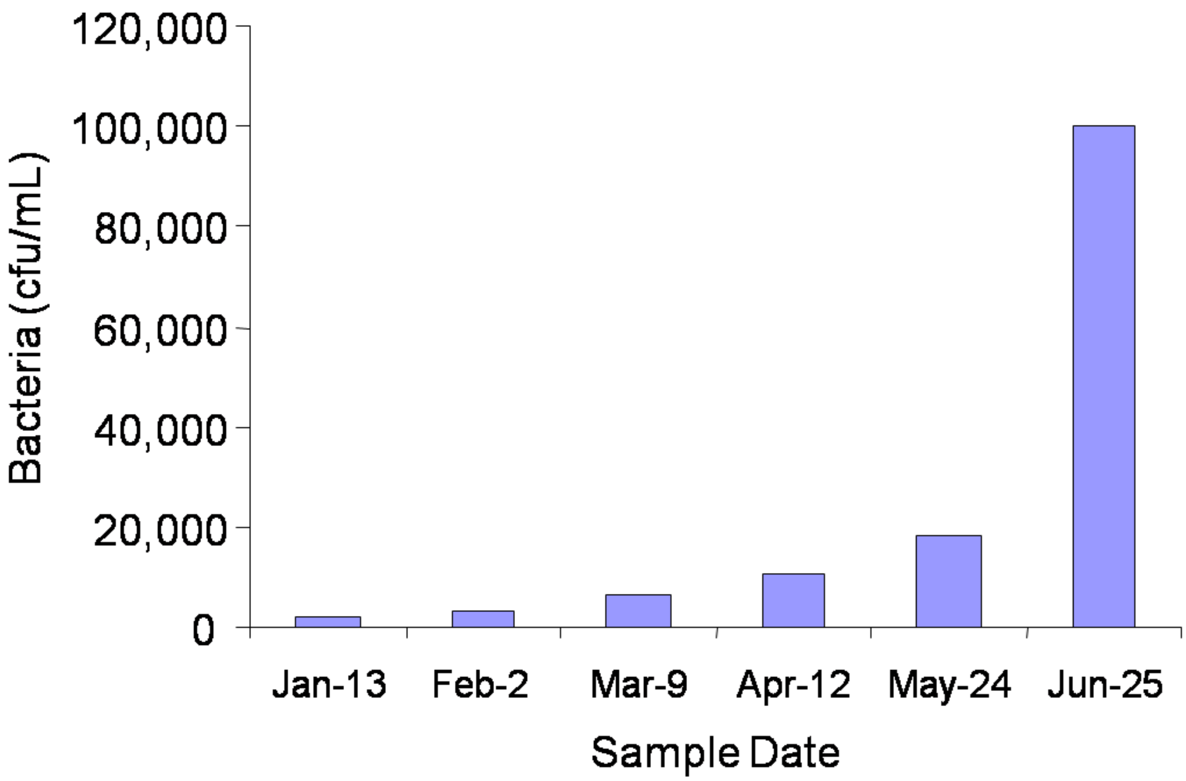

Figure 5.1. Increasing biological load (bacteria count in colony-forming units per milliliter) in a tank of non-recirculated irrigation water tank at a commercial greenhouse sampled during the spring. Laboratory analysis by Selective Micro Technologies, research by Paul Fisher (University of Florida) and Cheryl Smith (University of New Hampshire).

Oxidation-reduction potential

Volumetric injection and measurement of chlorine concentration can be combined with the measurement of oxidation-reduction potential (ORP). Oxidation-reduction potential is read in millivolts (mV) and measures the oxidative power of the treated water. Oxidation-reduction potential is a proven technology for municipal water treatment and food safety.

An oxidation-reduction potential level of 650 to 750 millivolts is typically used to indicate adequate sanitation based on killing of human pathogens. Research is ongoing to refine oxidation-reduction potential levels suited for plant production.

Control using chlorine and oxidation-reduction potential is ideally undertaken with inline sensors and dosage systems. This method of control can be applied to dosage of all chlorine forms (gas, liquid and solid), as well as some other oxidizing chemicals. An additional controller for water pH is also needed where water is acidified.

In a low-tech installation without inline controls, water pH and free chlorine can be measured weekly using calibrated handheld meters (cost $150 to $400). Handheld oxidation-reduction potential meters are also available.

At the University of Florida, tests with commercially available ExTech oxidation-reduction potential and chlorine meters and a Hanna oxidation-reduction potential meter have yielded results similar to a higher-cost laboratory sensor.

Tips for using sodium and calcium hypochlorite

- Chlorine should be combined with other water treatment components such as filtration and aeration to increase efficacy.
- Store liquid sodium hypochlorite protected from ultraviolet light, either at low temperatures (60°F-70°F) or in smaller volumes so that material is turned over in 15 days (degradation rate doubles for each 10°F temperature increase).
- Store solid calcium hypochlorite in a dry location.
- At the low chlorination rates (below 2 ppm) used for constant treatment, sodium, calcium or chlorine will not significantly affect plant nutrition, water electrical conductivity, calcium deposits, or pipe corrosion. However, when handling concentrated chlorine, use injectors and piping designed for caustic chemicals.
- Because chlorine can react with some metals and plastics, check with the manufacturer of your irrigation system components to make sure that problems will not occur if chlorine is injected.
- Follow guidelines for operator safety and handling. Never mix concentrated chlorine with other chemicals.

Greenhouse uses liquid bleach to treat water

Michael's Greenhouses in Cheshire, Connecticut, operates 5 acres of greenhouses and 15 acres of outside growing area. The company produces plants year-round to sell to garden centers.

Several years ago a large water storage tank was installed to increase water availability during peak irrigation times. However, Michael's well was contaminated with iron bacteria. The bacteria clogged the boom irrigation nozzles, severely damaging plant quality and increasing labor costs.

A Hanna Instruments chlorination system was installed to dose sodium hypochlorite (bleach) into a circulating loop in the storage tank. The system (Figure 5.2) included an (ORP) controller, probes, chlorine injector, and a process chlorine analyzer (PCA).

Chlorine is injected into the tank via the circulating loop, the oxidation-reduction potential is maintained at 650 millivolts (mV), and oxygen is also pumped into the tank. This system has dual safety controls, including metering the chlorine via oxidation-reduction potential and a second control based on chlorine concentration.

The chlorination system has provided clean irrigation water, with reduced algae growth and no clogged nozzles. The cost to treat Michael's water is about $40 per year for chlorine bleach. This low cost resulted from the synergistic benefit of aeration, filtration and controlling the chlorine injection via oxidation-reduction potential.

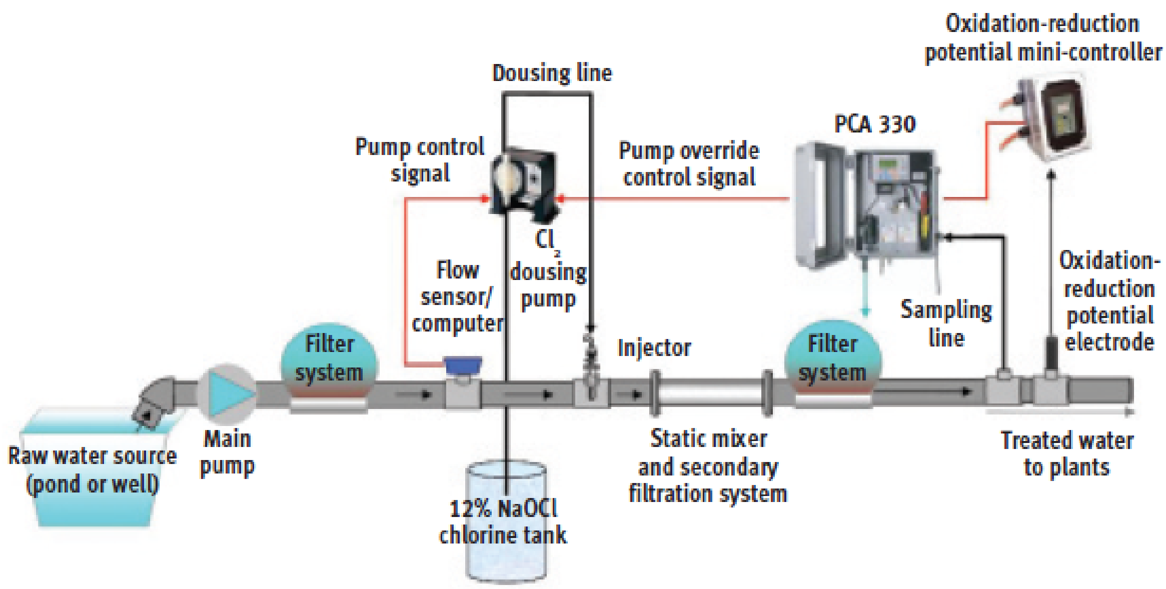

Figure 5.2. System diagram to inject and control liquid chlorine (sodium hypochlorite).

Using calcium hypochlorite for chlorination

A nursery wants to control *Phytophthora* in its irrigation water, which is pulled from a surface pond. Water was pumped from the pond six hours per day at 550 gallons per minute. The company installed a water-treatment system that dosed chlorine using calcium hypochlorite tablets.

The Accu-Tab System chlorinator consists of a rigid PVC cylinder with a sieve plate resting above the bottom of the unit (Figure 5.3). Incoming water from a side stream contacts only the tablets at the bottom of the feeder, so remaining tablets stay dry and do not dissolve prematurely. The tablets erode at a predictable rate dependent upon water flow to the unit. Chlorine dosage is controlled by the water flow rate through the chlorinator. The chlorinator effluent is then returned to the un-chlorinated main system flow providing the desired level of available chlorine (Figure 5.4).

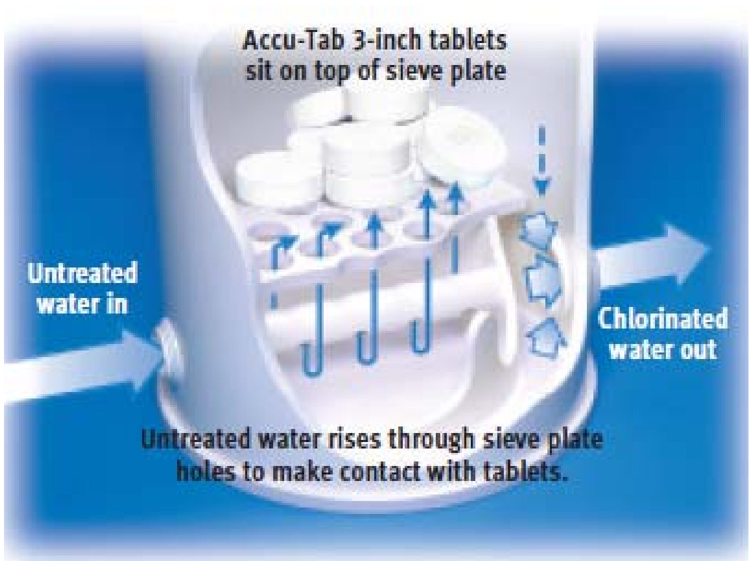

Figure 5.3. Diagram of a calcium hypochlorite chlorinator.

The chlorinator installed by the nursery holds 75 pounds of tablets, which are recharged weekly. The system also includes a flow meter, gate valve, chlorinator, saddle clamp and PVC pipe costing a total of $1,005 including the chlorinator and installation. The system had no moving parts and low maintenance. This application did not require electricity or additional sensors, but the chlorinator could be controlled via oxidation-reduction potential and inline sensors if preferred.

To calculate operational costs of the system, it is necessary to determine how much chlorine is going to be used by the calcium hypochlorite chlorinator. Published literature indicates that maintaining 2 ppm free chlorine **residual** in the line inactivates multiple species of *Phytophthora*. However, more than 2 ppm must be injected since surface water has some **demand** in the form of organic material and algae. Surface water demand fluctuates between 2-5 ppm chlorine with the season. Using an average of 3.5 ppm demand plus 2 ppm residual requires a total of 5.5 ppm. The cost to generate this much chlorine would be 17 cents per 1,000 gallons of treated water.

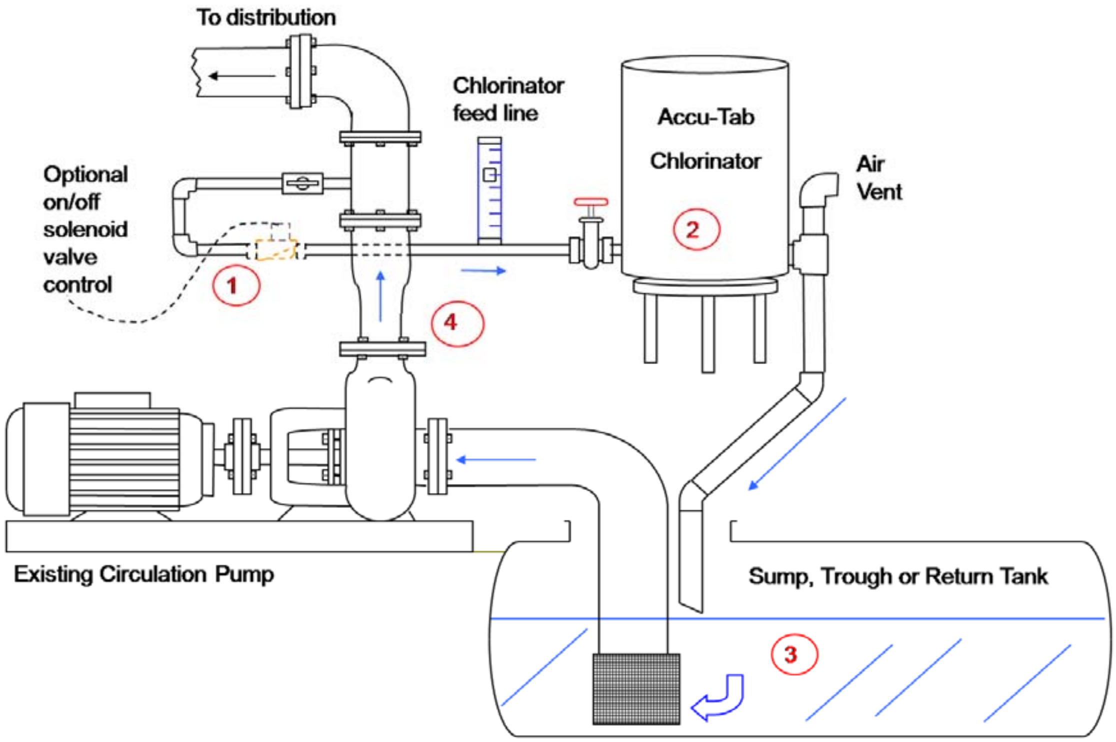

Figure 5.4. System diagram for calcium hypochlorite.

How it Works:

1: When the pump starts, water from the sump is pumped into the discharge line. The solenoid opens and a small side stream of pressurized water flows through the chlorinator feed line, flow meter, and control valve.
2: The water contacts the Accu-Tab tablets in the chlorinator and erodes a controlled, predictable amount of chlorine.
3: The chlorinated water drains next to the pump suction and is immediately pulled into the pipe and thoroughly mixed.
4: Treated water is pumped into the distribution network. When the pump stops, the solenoid valve closes and the chlorinator stops. The control valve allows precise chlorine residual control: high flow rates for "shock" treatments or lower flow rates for maintenance chlorination.

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This article is the fifth in a twelve-part series originally published in GMPro Magazine.

6. Gas Chlorination Can Sanitize Water

By Jill Marie Majka, Bill Argo, Paul Fisher, and Chuanxue Hong.

Gas chlorination is used successfully in nurseries to control pathogens such as *Phytophthora* and *Pythium*, in addition to algae and iron bacteria. In this article, we describe technical aspects of gas chlorination, with the example of Lancaster Farms, a wholesale nursery in Virginia that has used gas chlorination in their recycled irrigation water since 1979.

Chlorine gas can be injected directly into irrigation water, using an ejector designed to improve safety and precise dosage. Chlorine gas reacts quickly with water to form hypochlorous acid (a sanitizing agent) and hydrochloric acid, as follows:

Chlorine gas (Cl_2) + water (H_2O) → hypochlorous acid (HOCl) + hydrochloric acid (HCl)

Chlorine gas has a slightly acidic effect on irrigation water pH at low concentrations (0.5 to 10 parts per million (ppm) free chlorine at the chlorine source). This acidity is an advantage because sanitation from hypochlorous acid is most effective at a slightly acidic pH.

Greenhouses that have high alkalinity water sometimes provide additional acid injection (usually sulfuric acid) to maintain the water pH in the optimal range of 6-7.5 for hypochlorous acid, or inject a higher dose of chlorine. When setting up an acid-injection system, inject the acid first for pH control before injecting the chlorine gas.

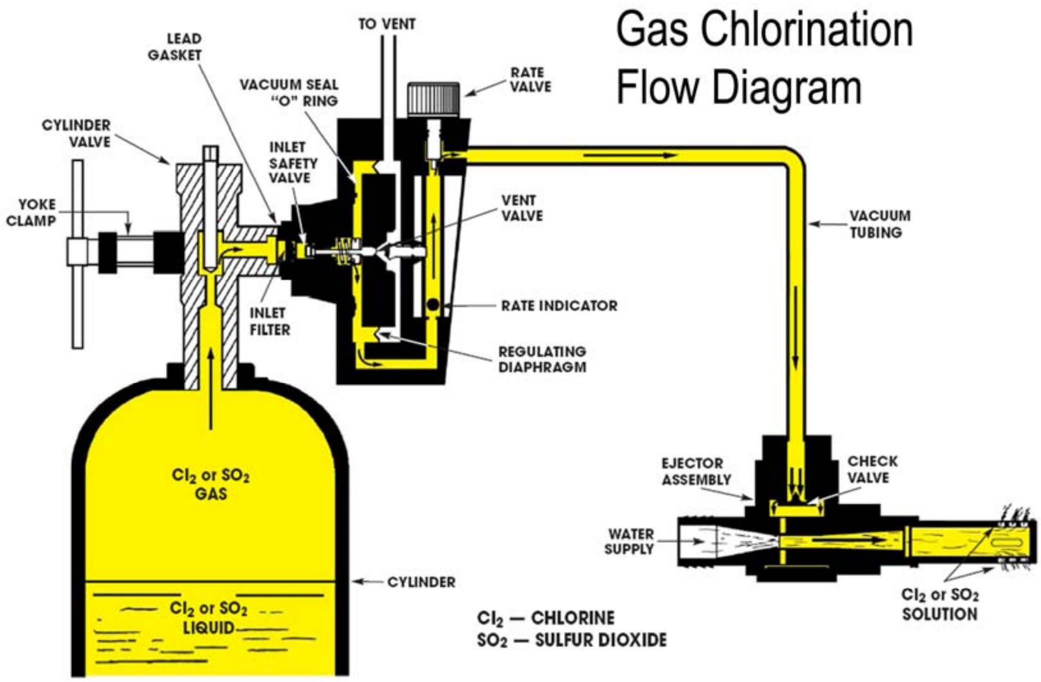

Figure 6.1. A gas chlorination flow diagram. Image courtesy of Chlorinators Incorporated.

When chlorine gas is applied continuously (the most commonly used method), enough chlorine is injected to maintain 0.5 to 2 ppm of free residual chlorine at remote outlets in the irrigation system. Research has found that 2 ppm of free residual chlorine at pH 6-7.5 successfully controls zoospores of *Pythium* and *Phytophthora*. This level of chlorine also controls algae and slime from iron bacteria.

When, where to inject gas

Algae and iron bacteria, which cause slime to form in irrigation lines or filters, can be controlled with chlorine gas. However, chlorine gas is most effective for preventive maintenance on a new or clean irrigation system. An irrigation system already clogged with bacterial slime or deposits should be cleaned and sanitized before chlorine gas will be effective.

Gas chlorine should be injected ahead of water filters. Chlorine passing through the filters prevents bacterial growth from occurring inside each filter. Treating with chlorine immediately after back-flushing reduces the amount of chlorine required and minimizes the sticking action of slime that becomes trapped in the filter.

To improve safety, manufacturers have developed chlorine gas ejectors that work on a vacuum principle (Figure 6.1). A venturi ejector creates a vacuum, which actuates the gas ejector. This design prevents chlorine gas from being added unless the irrigation system is operating so that the gas is immediately dissolved in the irrigation water.

Chlorine gas released into the air is toxic. As with other sanitation chemicals, it is essential to use injection equipment designed with safeguards and to train employees how to correctly operate the equipment.

Chlorine gas costs about $1 per pound (average U.S. cost). Depending upon water quality and chlorine demand, one pound of chlorine gas can treat 24,000 gallons of irrigation water, based on a dosage of 5 ppm. The operating cost of chlorine gas is very favorable compared with other sanitation chemicals.

Gas chlorination works for Lancaster Farms

Gas chlorination isn't a new idea. Almost three decades ago, the operators of Lancaster Farms, a 200-acre wholesale container nursery in Suffolk, Virginia, discovered that the recycled water in the company's irrigation system was introducing disease pathogens to all of its nursery stock, especially *Phytophthora* and *Pythium* in azaleas. As a result, the nursery installed chlorine gas treatment equipment in 1979 to clean and maintain the irrigation system.

"Pathogens in our recycled water got to be so bad, it was about to put us out of business," said Bill Daughtry, Lancaster Farms vice president, herbicides and water specialist.

"We tried fungicides of different combinations and rates, but nothing seemed to take care of the problem. We knew of a nursery in New Jersey that was using chlorine gas. We thought they were crazy," admits Daughtry, "but when gas chlorinators changed to vacuum systems they became much safer."

Figure 6.2. Bill Daughtry, Lancaster Farms.

Lancaster Farms initially installed a gas chlorinator in only one pump house. "We couldn't believe the difference it made in just 30 days, so we installed them in the other pump houses," Daughtry said. "It turned the whole nursery around. Our plants were so much healthier, we stopped carrying them to the dump and started putting them in the bank! We paid for the equipment the first year and it cut our fungicide costs in half."

Proper handling and training are key components with gas chlorination (as with all treatment chemicals.) Lancaster Farms has trained a select group of four employees to operate the gas chlorinators.


Figure 6.3. Lancaster Farms, Suffolk, Va.

Lancaster Farms uses 1.3 million gallons of water per day that is treated with continuous gas chlorination. Sixteen Regal gas chlorinators treat the water pumped from six ponds. Daughtry said the direct-cylinder-mounted gas chlorinators are quick to install and easy to use and maintain.

For more: Lancaster Farms, (800) 336-2200; www.lancasterfarms.com. Chlorinators Inc., (800) 327-9761; www.regalchlorinators.com.

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This article is the sixth in a twelve-part series originally published in GMPro Magazine.

7. Using Chlorine Dioxide for Water Treatment

By Paul Fisher, Bill Argo, Jinsheng Huang, Peter Konjoian, Jill Marie Majka, Lars Marohn, Alan Miller, Robert Wick, and Rick Yates.

Chlorine dioxide (ClO_2) is an effective sanitizing agent for water treatment. In horticulture, it is used at a high concentration to remove established biofilm that lines irrigation systems, clogs emitters, and can potentially harbor pathogens. For continuous application, a low concentration of chlorine dioxide can be used to maintain clean irrigation lines and to inhibit algae and diseases.

Mode of action

The chemistry of chlorine dioxide differs from gas chlorine, sodium hypochlorite (bleach), or calcium hypochlorite (tablets), which react with water to form sanitizing hypochlorous acid. Chlorine dioxide is a gas generated onsite in the nursery when reagents react in a stock tank. Once injected into water, chlorine dioxide remains as a high soluble, dissolved gas. Chlorine dioxide is neutral to slightly acidic (Figure 7.1), and is effective at a wide pH range (4 to 10) for irrigation water (Figure 7.2).

The chlorine dioxide molecule is a strong oxidizer, with greater oxidizing power than other forms of chlorine at the same concentration (Figure 7.3), and is particularly effective at penetrating and removing biofilm. Chlorine dioxide is more expensive on a part per million basis for treating large volumes of water compared with other chlorine forms. Therefore, some growers use chlorine dioxide in highly disease-sensitive areas of the greenhouse such as plant propagation, rather than treat the entire irrigation system.

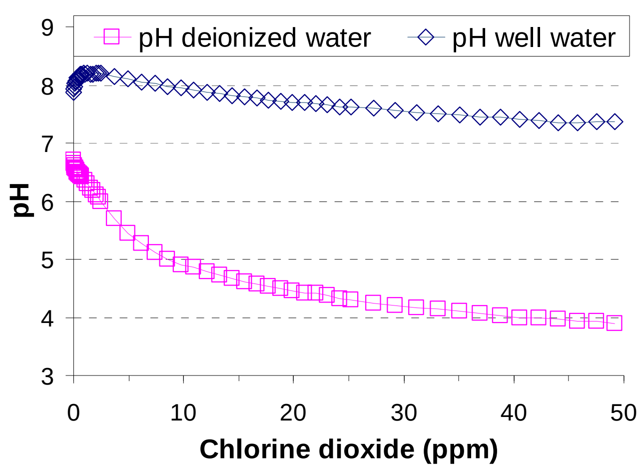

Figure 7.1. Chlorine dioxide, generated from Ultra-Shield, is slightly acidic. Two water sources were used: deionized water with no alkalinity, and well water with 100 parts per million calcium carbonate ($CaCO_3$) alkalinity. Research by the University of Florida.

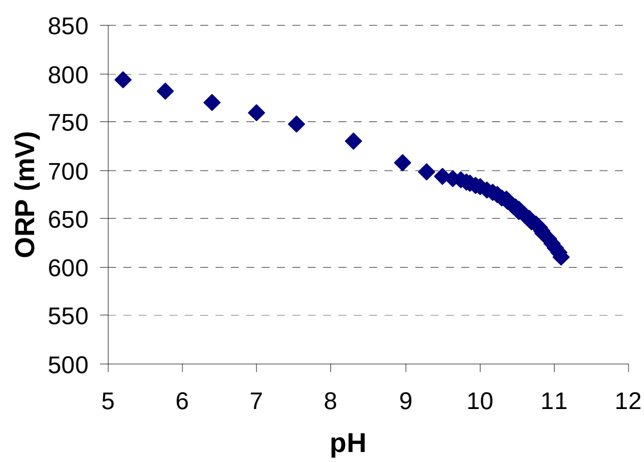

Figure 7.2. Chlorine dioxide, generated from Ultra-Shield at 2.5 ppm in deionized water, has high oxidizing power (as indicated by an oxidation-reduction potential above 650 millivolts) across a wide pH range. Research by the University of Florida.

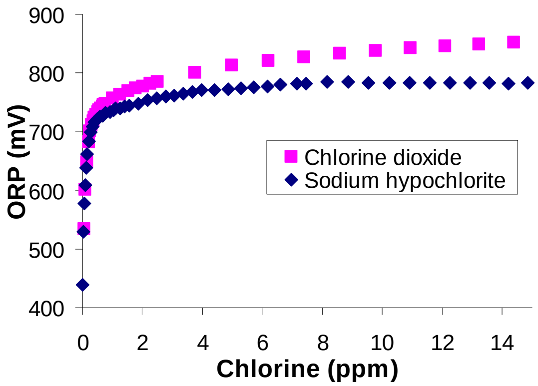

Figure 7.3. Chlorine dioxide is a stronger oxidizer than other chlorine forms like sodium hypochlorite at concentrations in parts per million. Chlorine dioxide was generated from Ultra-Shield in deionized water and sodium hypochlorite was generated from Clorox regular strength bleach. Water pH was 4.7-6.7 for chlorine dioxide and 5.5-7.5 for sodium hypochlorite. Research by University of Florida.

Shock treatment

Label rates recommend a shock treatment of 20-50 ppm chlorine dioxide (depending on the product) maintained for 12 hours. If the concentration of chlorine dioxide decreases significantly over the 12 hours, then reapplication is needed. With any shock treatment, do not use the irrigation system until it has been thoroughly rinsed and flushed with clean water because of the significant risk of phytotoxicity. It is best to perform the shock treatment between cropping periods or in empty growing zones. Avoid running the shock solution through emitters that will be clogged by deposits in the line.

For continuous treatment, inject sufficient product at the water source to provide a residual concentration (at the furthest outlet) of 0.25 ppm chlorine dioxide measured with either test strips or a meter (Figure 7.4). Growers have found that after a shock treatment, 0.25 ppm residual chlorine dioxide is effective to maintain irrigation lines free of biofilm. The initial concentration at the water source needs to be somewhat higher than 0.25 ppm in order to meet the demand from organic load and other components in the water.

Figure 7.4. Chlorine dioxide concentration can be measured with a meter or test strips. Photograph by Peter Konjoian.

Exposure rates

Australian research found that exposure to 3.3 ppm of chlorine dioxide for 10 minutes killed spores of *Alternaria zinniae*, *Fusarium oxysporum*, *Colletotrichum capsici*, *Phytophthora cinnamomi*, and *Pythium ultimum*. Studies by University of Massachusetts found that 1 ppm chlorine dioxide from Selectrocide provided control of *Pythium aphanidermatum* zoospores, whereas *Fusarium oxysporum* required treatment at 5 ppm for 20 minutes and *Erwinia chrysanthemi* bacterial cells required at least 20 ppm for control.

Plants should not be exposed to more than the 0.25 ppm rate unless specified on the product label. Product tests have found phytotoxicity at 1-2 ppm chlorine dioxide when water was applied repeatedly to impatiens and geranium foliage in mist propagation. Periodic applications of chlorine dioxide to roots or foliage are less sensitive to than continuous mist propagation above 0.25 ppm. Phytotoxicity testing in your situation on a small group of plants, as with any agrichemical, is recommended.

Although growers have not reported plant micronutrient deficiencies when using chlorine dioxide, research has demonstrated that the presence of micronutrients in the irrigation water will increase the chlorine demand of the water. For example, researchers at USDA-Agricultural Research Service and Washington State University found that 0.6 ppm of ClO_2 was needed to kill 50 percent of *Fusarium oxysporum* conidia in pure water, but the lethal dose increased to 1.9 ppm after 10 minutes of mixing with 1 ppm of iron, manganese, copper, and zinc fertilizers. This result emphasizes the complex reactions that occur when a sanitizing agent is mixed with irrigation water.

Chlorine dioxide products

Chlorine dioxide must be generated onsite. In the past, large-scale chlorine dioxide generators used in other industries faced technical challenges when applied to greenhouses, including the variable water and chlorine dioxide demand over time. In contrast, newer chlorine dioxide products that are U.S. EPA registered for greenhouse use are easy to use and highly effective. Chlorine dioxide is safe when used according to label instructions, but gas released into the air is toxic and must be ventilated properly. Ultra-Shield and Selectrocide are two chlorine dioxide products labeled for the greenhouse market. Both products cost less than 1 cent per gallon of water treated at a 0.25 parts per million residual level.

Ultra-Shield

Whitmire Micro-Gen Inc. launched Prescription Treatment Brand Ultra-Shield (Chlorine Dioxide Water Treatment) in 2008. The product generates a solution of chlorine dioxide from tablets that dissolve in water in under 20 minutes, producing a solution that is ready to inject into irrigation lines (Figure 7.5).

Figure 7.5. Algae present without chlorine dioxide treatment (top) and greenhouse floor following chlorine dioxide treatment (bottom) with Ultra-Shield at 0.25 ppm for 14 days continuously in the irrigation water.

Ultra-Shield is labeled for shock (20 parts per million for 12 hours) or continuous treatment, in addition to disinfestation of greenhouse surfaces. Ultra-Shield can control pathogens that build up or are carried through recirculating and non-recirculating irrigation systems, hard non-porous surface areas in all production, growing and holding areas like equipment, benches, containers, tools, irrigation lines, evaporative cooling systems, tanks, transfer lines and containers (Figure 7.6). It can be used in ornamental greenhouses, nurseries, shade houses, garden centers, floral shops, propagation houses and related systems. The product uses common greenhouse equipment resulting in low startup costs and requires little labor to operate other than initial set-up and stock tank monitoring.

Figure 7.6. Plants grown without (top) or with (bottom) chlorine dioxide (Ultra-Shield at 0.25 ppm for 14 days) applied continuously in the irrigation water. Note algae growth in top photo.

Selectrocide

Selective Micro Technologies launched the product Selectrocide in 2006. A highly pure solution of chlorine dioxide is generated by placing a dry packet in water, yielding six gallons of 500 parts per million stock solution within 12 hours. This stock solution is generated at neutral pH, is stable for about two weeks, and can be injected into irrigation lines with common injection equipment. Contaminated irrigation lines can be cleared of algae and biofilm buildup by an initial shock treatment of two consecutive overnight charges of 50 ppm.

Cost of treatment depends on the volume of the system, calculated by estimating pipe lengths of main and secondary lines, and any additional connected lines that are to be treated. A 50 ppm solution costs approximately $65 per 100 gallons. As a reference, the volume of 100 feet of 1- and 2-inch diameter PVC pipe is 4 and 16 gallons, respectively.

Once the irrigation lines are treated, continuous injection of approximately 0.5 parts per million is recommended to prevent re-establishment of biofilm in the lines, leaving a residual concentration of approximately 0.25 parts per million in the water as it leaves the irrigation line.

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This article is the seventh in a twelve-part series originally published in GMPro Magazine.

8. Using Activated Peracids for Water Treatment

By Robert Larose, Paul Fisher, Emily Austen, Vijay Choppakatla, Anne Frances, Easton Horner, Jinsheng Huang, Robert Wick and Rick Yates.

Peracids, also called activated peroxygen, are a formulation of hydrogen peroxide (H_2O_2) and acetic acid that produce a highly reactive product called peroxyacetic acid (PAA). While peracids share some of the characteristics of sodium hypochlorite (they are manufactured as liquid concentrates and are classified as oxidizers), they are different from chlorinated products.

Properties of peracids

Peracids use hydrogen peroxide as their base component. Hydrogen peroxide is a common chemical compound found in most people's medicine cabinets for disinfecting cuts and bruises, among other uses. Hydrogen peroxide is produced by joining two hydrogen molecules with two oxygen molecules (Figure 8.1). The bonds that hold the two oxygen and hydrogen molecules are generally weak, which makes hydrogen peroxide unstable. Store-brand hydrogen peroxide is packaged in brown bottles because even weak ultraviolet rays emitted from store lights can break the molecule bonds.

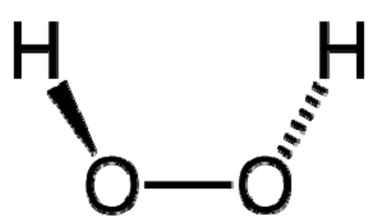

Figure 8.1. Chemical formula for hydrogen peroxide (H_2O_2).

Peracids combine hydrogen peroxide and organic acids, typically acetic acid, to form a new compound called peroxyacetic acid (Figure 8.2). This compound is an activated form of hydrogen peroxide and produces a much more stable and powerful oxidizing compound to treat pathogens and algae in water.

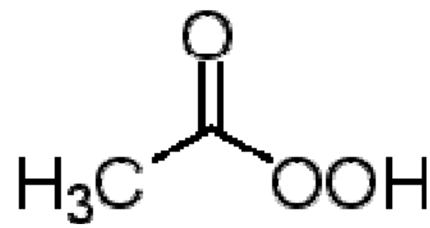

Figure 8.2. The peroxyacetic acid (PAA) molecule.

Peracids are acidic in nature. The typical pH value for most concentrates is 1.9. Concentrated material is highly reactive and is designated as both an oxidizer and a corrosive due to the acidity of the product.

Peracids tend to be very tolerant of pH fluctuations and are effective at an elevated pH value of 8, although the optimum pH for peracids is 7.0 or lower. Because peracids acidify water, they can be help to partially moderate problems of high pH or alkalinity in irrigation water (Figure 8.3).

Peracid products

Peracids such as BioSafe Systems ZeroTol Algaecide / Fungicide and SaniDate 12.0 Micro biocide contain peroxyacetic acid and inert stabilizers, surfactants and buffering agents that help maintain the bonds of the peracid compound. These stabilizers make the peroxyacetic acid resistant to degradation by ultraviolet light. Formulated peracid products are in equilibrium between hydrogen peroxide and peroxyacetic acid chemical forms.

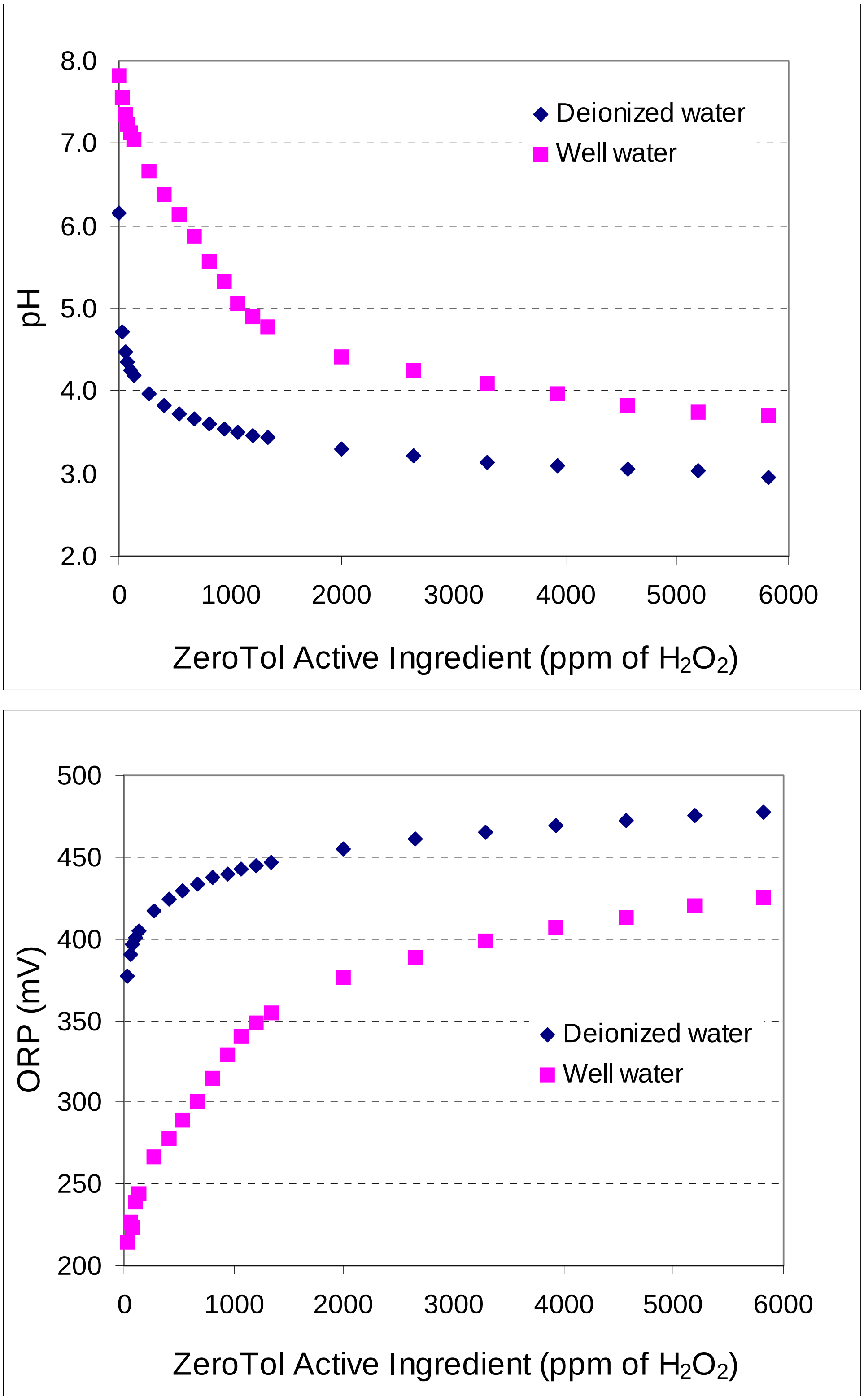

Figure 8.3. Effect of ZeroTol concentration on solution pH (top) and oxidation reduction potential (bottom) with deionized water or well water with 112 ppm alkalinity. Research by the University of Florida.

Increased concentration of peroxyacetic acid allows higher dilution rates as well as increased stability and resistance to organic degradation. Typical peroxyacetic acid concentrations are 2 percent, 5 percent and 12-15 percent. ZeroTol is 2 percent peroxyacetic acid and SaniDate 12.0 is 12 percent peroxyacetic acid.

The applied concentration of peroxyacetic acid and hydrogen peroxide varies depending on the formulation and product use. For example, label rates for SaniDate 12.0 range from 1.2 parts per million (ppm) peroxyacetic acid (1:100,000 dilution) for continuous low level application to irrigation water to 200 ppm peroxyacetic acid (1:600) for treatment of greenhouse surfaces. ZeroTol label rates range from 1 ppm peroxyacetic acid (13.5 ppm hydrogen peroxide, 1:20,000 dilution) to 400 ppm peroxyacetic acid (5,400 ppm hydrogen peroxide, 1:50 dilution) depending on the product use.

Formulated peracid products are more stable than hydrogen peroxide and degrade principally through reactions with elemental metals, microorganisms and organic material. For example, a 2 percent formulated peracid (ZeroTol) was prepared at 150 ppm of hydrogen peroxide in a subirrigation tank in a greenhouse trial run by BioSafe Systems. The tank solution maintained its efficacy for up to three days of use in a flood floor system before losing strength. A preliminary trial at the University of Florida confirms that the presence of organic matter is the main factor likely to decrease residual peroxyacetic acid and hydrogen peroxide in a ZeroTol solution.

Peracid concentration

The mode of action of peracids is by oxidation of cell membranes and penetration into cell structures of algae, bacteria and fungi. More specifically, peracids form free hydroxyl radicals (OH), which oxidize and disrupt thiol groups in proteins and enzymes.

Research by plant pathologist Robert Wick at the University of Massachusetts found that a 1:2,000 dilution of ZeroTol (135 ppm hydrogen peroxide, 10 ppm peroxyacetic acid) killed zoospores of both *Pythium aphanidermatum* and *Phytophthora parasitica*. The number of viable chlamydospores of *Fusarium oxysporum* was also reduced by nearly 80 percent using a 1:2,000 dilution of ZeroTol. ZeroTol activity against *Fusarium* was not reduced by the presence of peat in the solution over a 30-minute period.

Test kits are available to measure peroxyacetic acid levels (Figure 8.4). Even though peracids work by oxidation, their concentration cannot be accurately measured using an oxidation/reduction potential sensor, because oxidation/reduction potential is not very sensitive to peroxyacetic acid concentration (Figure 8.4).

Figure 8.4. Peroxyacetic acid concentration can be measured with a colormetric test kit or test strips.

Peracid greenhouse applications

Several features make peracids an excellent choice for agricultural and horticultural water treatment. First, peracid products that have been specifically formulated for horticulture offer a high degree of safety with regard to phytotoxicity.

With formulated peracids, the grower can easily adjust the concentration of active ingredient in the treated water to account for increased biological loading. This is important since many forms of bacteria and fungal organisms in their oospore life stage are very susceptible to low levels of peracids but organisms such as Pythium require higher active ingredient levels. Peracid products can be used for sanitation of greenhouse surfaces, shock applications for tanks and piping, continuous application at a low concentration, and also as a bactericidal or fungicidal application to plant foliage or roots.

A further advantage is that when peracids degrade, the byproduct is oxygen, which is a safe and beneficial byproduct. Oxygen is released through the process of breaking the bonds that hold oxygen and hydrogen together. You can see this process when you use hydrogen peroxide as an antiseptic to treat an open wound. The visible bubbling is a release of oxygen and results from the peroxide compound breaking apart through a reaction with iron and other proteins and enzymes present in the blood.

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This article is the eighth in a twelve-part series originally published in GMPro Magazine.

9. Water Treatment with Copper Ionization

By Ratus Fischer, Paul Fisher, and Anne Frances.

Modern copper ionization treatments are more effective, precise and environmentally responsible than their older counterparts. Copper has been used for centuries as a fungicide, mostly in the form of copper sulfate or mixed with lime as Bordeaux mixture. You may be familiar with traditional copper sulfate fungicides that were applied to grape plants and left blue stains on the leaves.

The modern process of copper ionization uses electricity to harness the natural molecular properties of copper. Because soluble copper ions lack two electrons, they are "eager" to bond with other suitable atoms that can supply the missing electrons. When copper ions encounter organic matter, including plant pathogens, they firmly attach themselves and disrupt the pathogens' cell walls, killing the organisms.

Studies by professor Walter Wohanka at Geisenheim Research Center in Germany and in the United States demonstrated that 0.5 to 1 parts per million (ppm) of free copper significantly reduced *Pythium*, *Phytophthora*, *Xanthomonas* and other waterborne pathogens, while 1 to 2 ppm effectively reduced algae.

How copper ionization works

In water treatment systems, copper ions are created by submerging copper electrodes into the water stream. An electric current (DC voltage) is applied between the electrodes and the resulting current displaces copper atoms from one of the electrodes. The copper atoms are then carried away by the water flow. The "free" copper is actually not totally free because the copper ions immediately form weak bonds with water molecules. However, as soon as the copper ions find more attractive partners, they abandon the weak bonds for the stronger ones. Copper ionization systems can include a magnetic water conditioner, which enhances the copper ion's ability to attach to pathogens.

Copper ionization systems have been marketed to U.S. growers for quite a few years, but the results from traditional treatment systems were mixed. Although some growers experienced great reductions in waterborne disease pathogens like *Pythium* and *Phytophthora*, other growers saw no effect at all. Because of its variable results, copper ionization was filed into the snake-oil category.

Improved effectiveness

One reason that copper ionization was effective for only some growers is that copper atom output changes depending on the water flow and electrical conductivity. As the electrical conductivity fluctuates with the quality of the water, especially in pond and recirculation systems, the electrical current between the electrodes also changes. Systems are now available that automatically adjust copper output to the flow rate of the water, and compensate for the electrical conductivity of the water (Figure 9.1). By keeping the electrical current constant, the copper output remains constant. It is therefore possible to set a desired ppm concentration that remains stable independent of the water.

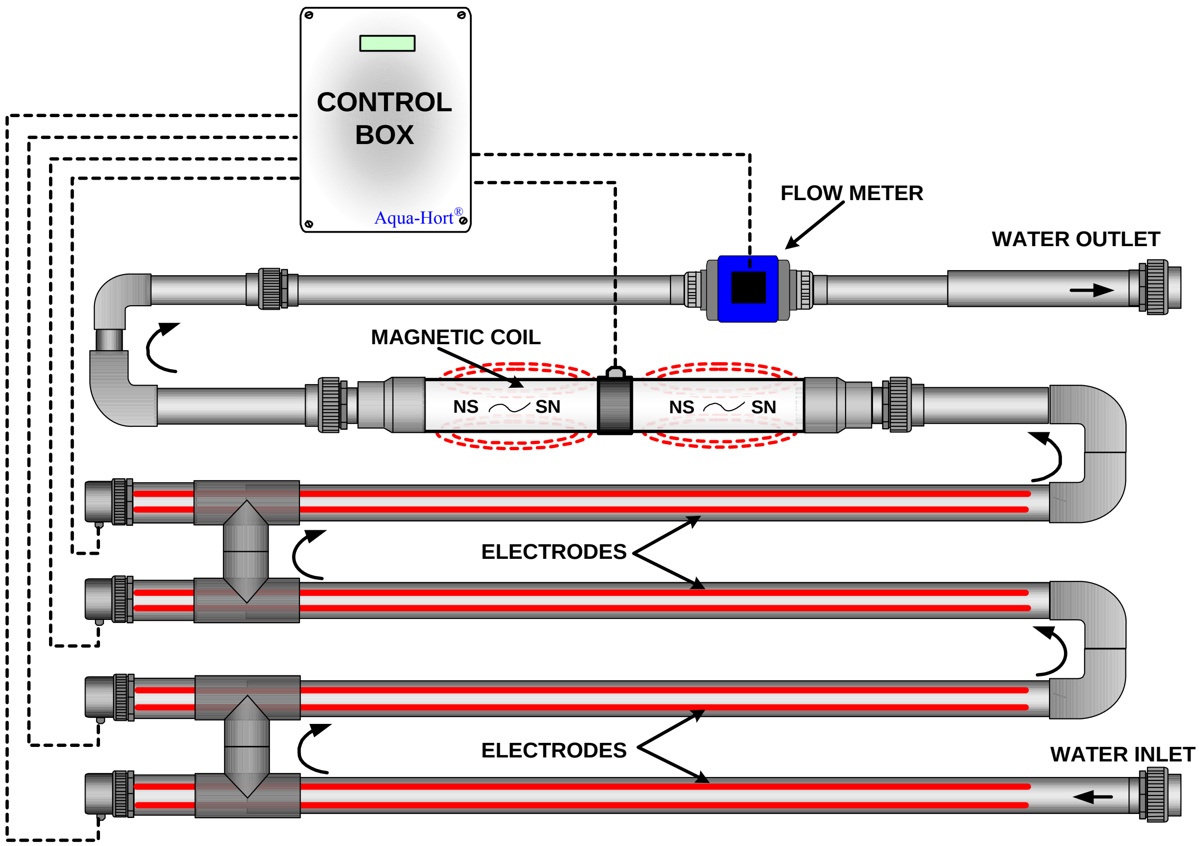

Figure 9.1. This AquaHort copper system is equipped with copper electrodes inside pipes. An electrical current passes through the system to turn solid copper metal electrodes into soluble copper ions. A magnetic coil increases activity of the copper ions. The control box corrects ionization rate based on water flow and water electrical conductivity to maintain a constant copper concentration.

Copper ionization has proven to be a cost effective and practical way to reduce pathogen levels, especially in high flow situations. Copper ionization seems to be less affected by organic matter in the water than some other treatment options. This is especially important in pond water or re-circulating applications with substantial amounts of algae, soil particles and dissolved organic matter, such as humic acids in the water. It is still recommended to filter water before copper ionization, but requirements are not as stringent as for ultraviolet light and ozone, for example.

Properties of copper

Copper is also a plant nutrient. The amount of copper added to water for the treatment of pathogens is within the range of nutritional copper. Since plants normally do not take up more copper than they require, accumulation is not a problem. Peat and other organic growing media components absorb excess copper.

Copper pollution of leached water is not an issue when ionization systems are correctly designed and operated. These systems generate a low copper concentration and the copper is rapidly bound up by peat particles (a minimal amount of copper leaches from the pot after irrigation). In recirculating systems, collected water is not normally released into the environment. Even if copper-treated water is released into the environment, the copper concentration should be below the 1.3 ppm level permitted by U.S. drinking water standards, which is higher than the typical concentration needed to effectively control pathogens. Although the release of small amounts of copper fall within accepted safety standards, releasing significant amounts of copper-containing water is not a recommended practice.

Copper residual effects

Copper ionization is a residual water treatment. That means the copper ions travel with the water and therefore, treat the whole growing system, from water source to the plant roots. Ultraviolet light, another popular water disinfection treatment, has no residual effect. This means any contamination downstream of the treatment source would not be treated by ultraviolet light.

Many plug producers use copper ionization alone. However, copper can be combined with other technologies, such as filtration and ultraviolet light, to provide both point and residual treatment (Figure 9.2).

Figure 9.2. A copper ionization system can be combined with other water treatment technologies such as filtration.

Copper sanitizes the whole water and growing system, while ultraviolet light provides additional, but non-residual reduction of pathogens.

Selecting and maintaining a copper system

Copper ionization systems are simple to operate, require little maintenance and are safe for employees (Figure 9.3). Initial cost for a system starts around $5,000 depending on flow rate, electrical conductivity and other system requirements. Copper ionization systems can be designed for flow rates from a few gallons per minute to thousands. Automatic control of copper output is essential.

Figure 9.3. Installation of a copper ionization system in a commercial greenhouse operation.

Select a system specifically designed for horticulture, not for a simpler application suitable for swimming pools, etc. There is a trade off between copper ionization and other water treatment systems. Initial investment is higher for copper ionization than for oxidizers such as hydrogen peroxide or chlorine, but operating costs tend to be lower over the long term because copper electrodes only need to be replaced once every year or two.

Copper ionization applications

Some typical applications of copper ionization include:

- Eliminating pathogens from ponds before the water is distributed throughout the irrigation system.
- Sanitizing well or city water to protect susceptible crops and control algae growth on benches, floors and in pots.
- Maintaining clean water in recirculating flood floor and ebb-and-flow bench systems by adding copper ions to the holding tanks or water each time it circulates to and from the floor or bench.

Types of copper ionization systems

Depending on the application, copper ion systems are available in different versions, including:

- A closed system with copper electrode rods inside pipes, for water with an electrical conductivity over 0.3 and in-line pressurized systems.
- A closed tank with copper plate electrodes for water with a low electrical conductivity between 0.1 and 0.3. The greater copper surface allows enough current to flow though the water despite the low conductivity.
- An atmospheric tank with copper plates for low electrical conductivity when the water is discharged into an open tank. This system is the most cost-effective, is simple to build and maintain, and can easily handle flow rates of 1,000 gallons per minute or more.

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10. Ozone for Water Treatment of Pathogens and Algae

By Charlie Hayes, Les Evans, Paul Fisher, Anne Frances, Rick Vetanovetz, and Youbin Zheng.

Ozone is a strong sanitizing agent for treating pathogens and algae in irrigation water. In an ozone water treatment system, oxygen from the air is converted into ozone gas, which is then dissolved into water to form aqueous ozone. Although ozone is not widely used in greenhouses and nurseries in the United States, it is an established technology in Europe and in other U.S. sectors including fruit packing, municipal potable water treatment and waste water treatment in animal agriculture.

Ozone controls algae and pathogens in irrigation water by oxidizing constituents of cell walls before it penetrates inside the cell wall and oxidizes enzymes, proteins, DNA, RNA and cell membranes. Ozone is a strong enough oxidizer to remove biofilm from piping, but has a short residual time in irrigation water. Biofilm is a thin, resistant layer of microorganisms (i.e. bacteria, algae) that forms on and coats various surfaces.

Mode of application

To produce ozone, oxygen from the air is converted into ozone using a corona ozone generator, which uses electrical energy to cause some of the oxygen (O_2) to break apart and reform as ozone (O_3). The ozone is then dissolved in water. The most efficient method to dissolve ozone in water is with a venturi injector in a pressurized system (Figure 10.1).

Figure 10.1. An ozone water treatment system. The air-preparation system (small white tank) is behind the central skid, where oxygen is concentrated from the air. The central skid is where ozone is generated, along with an auto-control system, and an auto shutdown system with an ozone-gas sensor. Ozone is then injected into pressurized irrigation water in the large blue contact tanks at the right. Water then flows through the thinner tanks on left which are filled with a filtration medium. From the filter, the ozonated water goes out into the irrigation stream or to a storage tank.

The method of dissolving ozone in water is dependent upon the contaminant level as well as the water pressure, temperature and depth. An ultraviolet light-ozone generator (typically used in swimming pools) that bubbles ozone directly into an irrigation tank is ineffective because insufficient ozone is generated, and some of the gas is released into the air rather than dissolving in water.

Using ozone in a greenhouse application

Design of a commercial ozone system can be illustrated by a Midwest greenhouse operation that is currently installing a water treatment system. An ozone system will treat recycled water in irrigation tanks. The treated water will subirrigate plants on concrete flood floors. When the treated water is pumped onto the flood floor, the goal is to ensure that the recycled water has been cleaned of pathogens and algae rather than to provide residual control of pathogens.

Water in each irrigation tank is circulated through an ozone system several times each day. Once the water has been ozonated, it is returned to the tank. The flow of ozonated water is directed to ensure mixing of the ozone with non-treated water in a return tank.

Required dose for greenhouse use

System design and the required ozone dose depend upon the intended application of ozone. For overall sanitation and washing down greenhouse surfaces, a high dose of ozone should be used with spray equipment that minimizes the release of ozone into the air (“off-gassing”).

For water purification and pathogen control, a higher ozone dose is required to build up residual activity. This application requires water filtration before and/or after ozonation. Another ozone application is for biofilm destruction, where ozonated water is placed in a pressurized piping system for at least 30 minutes.

Although research data are not yet available for nursery and greenhouse applications (research is underway at the University of Guelph), industry recommendations for ozone concentration and contact time are:

- Dissolved ozone residual levels of 0.2 parts per million for as little as 30 minutes can destroy established biofilm.
- Dissolved ozone residual levels as low as 0.01-0.05 ppm can control algae.
- Residual level of aqueous ozone (in the water) should be below 1 ppm to avoid phytotoxicity to crops. However, long term exposure to gaseous ozone (in the air) even as low as 75 parts per billion (0.075 ppm) can reduce the growth of most plant species.

Ozone damage can manifest itself in various forms, ranging from acute symptoms (visible injury to foliage including stippling, chlorosis mottle, necrotic lesions and localized waterlogging) to chronic symptoms, including subtle changes in color, reduced growth and accelerated leaf senescence.

The need for filtration

The amount of organic material in a water source is a major factor affecting the efficacy of ozone. Mechanically removing as much of the organic load as possible before ozonation occurs reduces the size of the ozone-generating equipment needed, thereby lowering sanitation costs.

Like many sanitizing agents, ozone is often combined with other technologies to increase its efficacy. Pre-filtration allows ozone to work efficiently against pathogens and algae by removing organic particles and debris like peat moss and plant roots. The more filtration that occurs, the less the organic load that has to be treated by the ozone system, and the more likely that ozone molecules will kill the remaining algae and pathogen spores. In the case of the Midwest greenhouse operation, water will pass through a media-filter (a rotating drum of paper) to remove particles larger than 10 microns before ozone treatment.

Residual effects and persistence in greenhouse water

Because ozone is rapidly consumed by organic matter, its residual activity is short-lived in irrigation water. As ozone breaks down, residual compounds are produced including hydroxyl (OH) radicals, which are also effective, but short-lived, oxidizers.

The persistence of ozone in irrigation water also depends on the water temperature and pH. As water temperature increases, the half-life of ozone decreases. However, the ozone dose required for bacterial destruction also decreases with warmer water. While ozone efficacy is not pH-dependent, ozone's half-life decreases as the pH increases, especially above a pH of 7.

When ozone is added to fertigation solutions, there is the potential for the precipitation of micronutrients. Researchers at University of Florida plan to investigate this issue from a production perspective.

Monitoring ozone concentration

The most accurate way to monitor dissolved ozone is inline, or within the irrigation line itself. Dissolved ozone measurements are quite sensitive to changes in water pressure; a drop in pressure will give a lower than actual reading.

Dissolved ozone can be measured with test kits using reagents or with commercial monitors. Since ozone is an oxidizer, its activity can also be monitored using either an inline or hand-held oxidation-reduction potential meter. These meters are the least expensive while ozone monitors and controllers are the most costly. In a greenhouse setting, the monitoring and control system can measure oxidation-reduction potential constantly to sense whether the ozone demand of contaminants in the water has been met and residual ozone is present.

Environmental and worker safety

To ensure environmental and worker safety, it is necessary to implement measures to minimize the release of ozone into the air. Ambient ozone gas monitors should be installed in pressurized systems that automatically shut down the generator if a leak occurs. If ozone is used indoors, safety criteria set by the Occupational Safety and Health Administration must be met. Once ozone breaks down in water, there are no environmentally-harmful residual products.

Ozone systems should always be sold as a complete system, since all materials contacting higher residuals of ozone should be made of ozone resistant materials. Ozone injectors are typically made of Kynar, but Teflon, stainless steel and other oxidation-resistant materials can be used.

Comparing ozone to other sanitizing agents

- Aqueous ozone is a dissolved gas in water, like chlorine dioxide. Careful engineering to ensure dissolution of ozone gas and contact and mixing between the gas and irrigation water is an essential step in system design.

- Ozone is in the high initial capital/low operating cost category of treatment technologies, similar to copper ionization. Ozone-generating units typically cost over $10,000 to install. After installation the main operating expense is for electricity because ozone is generated electrically from air.

- Ozone is an oxidizer, like hypochlorous acid, hydrogen dioxide, activated peroxygen and chlorine dioxide.

- Since ozone is an oxidizer, its activity can be monitored using an oxidation-reduction potential sensor, as well as using direct measurement of ozone concentration.

- Pre-filtration is essential to remove particles of organic matter such as peat to allow ozone to work efficiently against pathogens and algae. Treatments such as ultraviolet light can increase the efficacy of ozone against certain contaminants by providing both point treatment and creating highly active hydroxyl (OH) radicals.

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This article is the tenth in a twelve-part series originally published in GMPro Magazine.

11. Using Ultraviolet (UV) Light for Water Treatment

By R. Peter Fynn, Paul Fisher, Anne Frances, and Bill Argo.

Ultraviolet (UV) light is a highly effective option to control pathogens and algae in irrigation systems. Ultraviolet light systems treat water passing through one point in an irrigation system. Because ultraviolet light lacks residual activity, it is combined with filtration, which removes organic matter and increases light transmission and residual sanitizing agents such as ozone or peroxide.

Differences in ultraviolet light

Ultraviolet light has a shorter wavelength than visible light, but a longer wavelength than X-rays. Ultraviolet light is invisible to the human eye. The electromagnetic spectrum of ultraviolet light is categorized according to wavelength, measured in nanometers (nm).

Ultraviolet A (black light)	400 nm–315 nm
Ultraviolet B	315 nm–280 nm
Ultraviolet C (germicidal)	280 nm–100 nm

Not all ultraviolet radiation has the same sanitizing effect because different wavelengths have different properties. Only the UV-C wavelength is useful for killing microorganisms. The other ultraviolet light wavelengths (UV-A and UV-B) are ineffective.

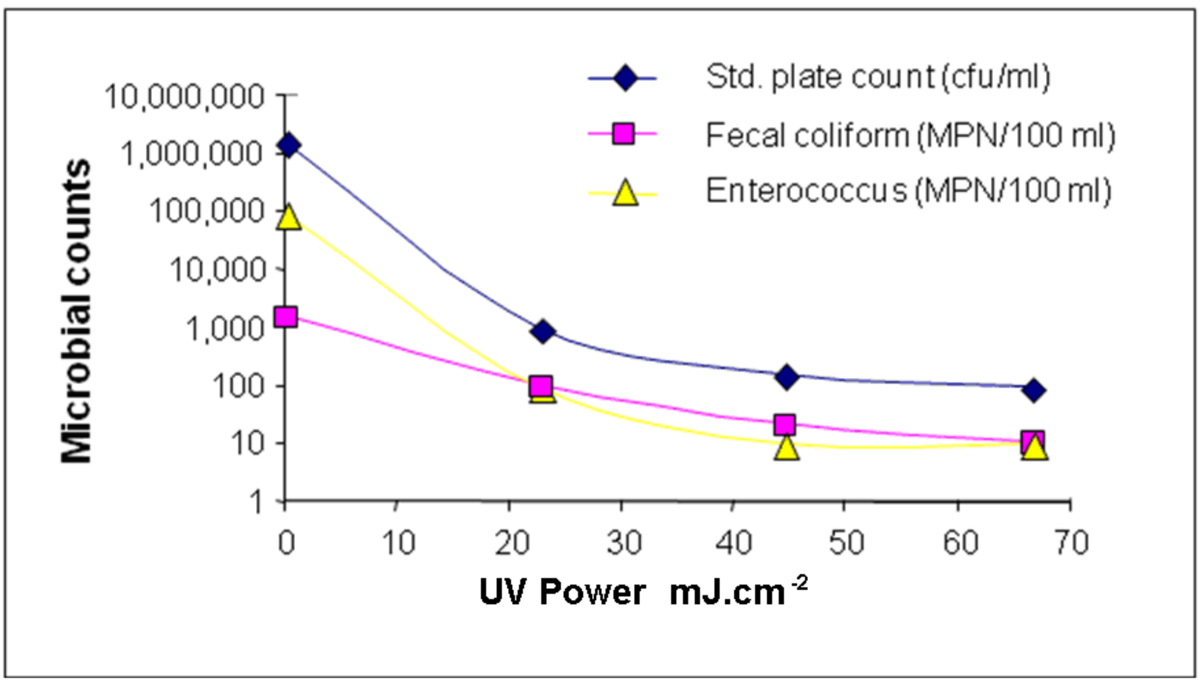

Figure 11.1. Increase in performance (bacteria kill) of an ultraviolet light system with an increase in the power (irradiation intensity) applied. Standard plate counts are measured as colony-forming units of bacteria per milliliter (cfu/mL). Estimated bacterial counts are presented as most probable number per 100 milliliters (MPN)/100 mL. Ultraviolet irradiance is expressed in energy per unit of surface area of water treated (milliJoules per square centimeter). Graph provided by Pure-O-Tech Inc.

Ultraviolet mode of action and dose

Ultraviolet radiation in the 240-280 nanometers (UV-C) range disinfects water through a purely physical, chemical-free process. An ultraviolet light bulb that emits a peak of 254 nanometer wavelength (UV-C) destroys the genetic information contained in bacteria, viruses and mold through a photochemical reaction. Bacteria lose their reproductive capability (become sterile) and are destroyed.

Increasing the ultraviolet light power increases the proportion of pathogens that are sterilized and killed (Figure 11.1). The ultraviolet light dosage required for a 99.9 percent reduction of microorganisms (known as a 3 log kill) varies according to the target microorganism.

Microorganism	**Power of ultraviolet light dosage (milliJoules per square centimeter)**
Bacteria	3.5–26.5
Viruses	6.6–440

Data from Pure-O-Tech Inc.

How ultraviolet light works

Ultraviolet light bulbs work by using an electrical ballast to form a discharge between two electrodes contained in a gas filled glass tube, similar to how fluorescent bulbs work (Figure 11.2). In an ultraviolet light bulb, the combination of the electrical discharge and the pressure and formulation of the gases contained in the bulb defines the wavelength of the emitted ultraviolet radiation. Ultraviolet light bulbs also contain a small amount of mercury so proper disposal is always recommended.

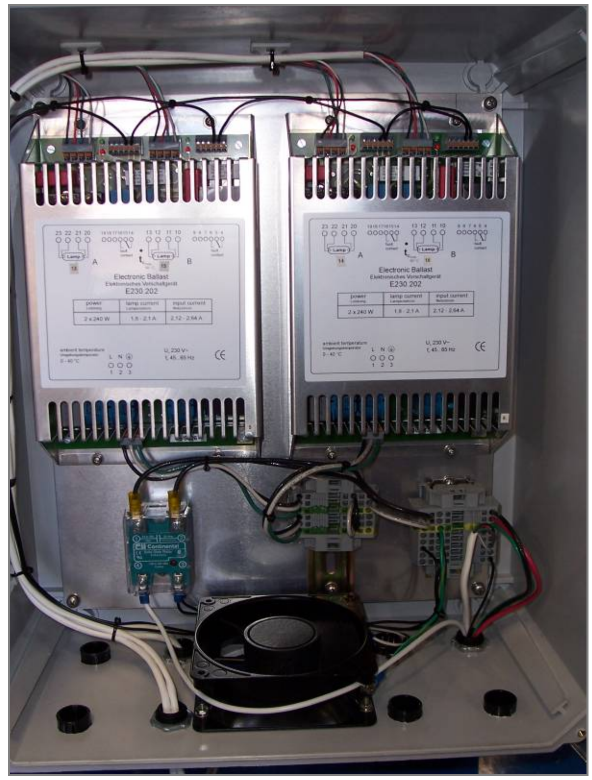

Figure 11.1. Two electrical ballasts, each drives two ultraviolet light bulbs.

Need for proper pretreatment

Ultraviolet light should be combined with filtration because suspended solids reduce the effectiveness of the ultraviolet treatment. Suspended solids (e.g., plant debris or algae) prevent radiation from penetrating throughout the enclosure in which irrigation water passes by the bulb. For this reason, it is essential that the water is pre-treated effectively.

The water entering ultraviolet light treatment should have a maximum turbidity of two nephelometric turbidity units (NTU is a common unit for turbidity). A value higher than two NTU will decrease ultraviolet light and reduce the effectiveness of the treatment.

Microbes have to "see" the ultraviolet radiation in order for it to be effective. If suspended solids in the water stream prevent the penetration of the ultraviolet radiation throughout the water volume, then microbes will be "protected" from the ultraviolet radiation and will not be killed.

The California standard is that the turbidity should be no greater than two NTU averaged over 24 hours, should not exceed five NTU for more than five percent of the time and should never exceed 10 NTU. In Florida the standard is a total suspended solids (TSS) maximum of 5 milligrams per liter as a single sample, but an average value is not specified.

Using ultraviolet light in an irrigation system

Ultraviolet light should be considered for recirculating water systems, or where growth of algae or disease organisms can cause problems. By treating water passing through ultraviolet light at one point in the irrigation system, the light does not create a build-up of chemicals in the water. Ultraviolet light is often combined with a technology that has residual activity, such as ozone, peroxide or copper, to continue sanitizing the water as it travels through the irrigation system.

Ultraviolet light enhances the efficacy of ozone or peroxide through the advanced oxidation process (AOP). Ozone is a very strong sanitizer that directly oxidizes pathogen cell walls. As ozone decomposes, radical by-products are created. These by-products are also very active sanitizers. When ultraviolet light is combined with ozone or peroxide, the resulting reaction forms more of the highly unstable and active hydroxyl radical, thereby increasing the sanitizing effect.

System design

It is essential to use a professionally installed system from a company familiar with the horticultural use of ultraviolet light. The major components of an ultraviolet light system include ultraviolet light lamps, lamp sleeves, piping and lamp cleaning, monitoring and control systems (Figure 11.3). When ultraviolet light is combined with ozone for advanced oxidation process, the system also includes an ozone generator and diffusers, ozone contactor, ozone off-gas decomposer, oxygen or air feed systems and supply and discharge pumps.

Figure 11.3. This ultraviolet light unit treats 100 gallons of water per minute and is equipped with high intensity bulbs (240 watts). Cost varies according to the water quality and the pretreatment that is required. Operating costs depend on the price of power. This unit requires 7.5 kilowatts to run.

The two primary design variables that must be optimized in sizing an advanced oxidation process system are the ultraviolet light power radiation per unit volume of water treated — more commonly referred to as ultraviolet dose — and the concentration of ozone. Ultraviolet dose, when applied to an advanced oxidation process, is a measure of the total lamp electrical energy applied to a fixed volume of water. The units are measured in kilowatt hour (kWh)/1,000 gallons treated. This parameter combines flow rate, exposure time to UV, and light intensity into a single term. The dose of ultraviolet light and peroxide/ozone required per unit volume of water treated will vary depending on the quality of the water to be treated.

Maintenance and precautions

Ultraviolet light bulbs, quartz sleeves and the ballasts need to be properly maintained. Ballasts come equipped with alarms that indicate when bulbs need to be replaced. Prompt replacement of bulbs is necessary to ensure continued treatment of the water stream. Bulbs can last up to 10,000 hours, but frequent on/off cycles can shorten bulb life dramatically. Inspection of the bulbs and quartz sleeves should be a regularly scheduled part of an ultraviolet light system maintenance plan.

For water disinfection, the ultraviolet light bulb needs to be enclosed in a suitable vessel such as a tube with the ability to seal the ends around the bulb (Figure 11.4). This can be achieved by enclosing the bulb in a sleeve which is sealed to the vessel. However, the sleeve has to be made of quartz because glass filters release some ultraviolet radiation, whereas quartz is largely transparent to ultraviolet radiation. The bulbs should be shielded so as to block radiation from passing into the surrounding space.

Figure 11.4. An ultraviolet light bulb (bottom) and quartz sleeve.

The quartz sleeves require periodic cleaning, so the system design should allow the sleeves to be easily removed. A common problem is calcium deposits on the sleeve exterior. The quality of the water being treated affects how often the sleeves need to be cleaned.

Calcium deposits can be removed by placing the sleeve in an acid bath. A common treatment method is to soak each sleeve in a vertical PVC pipe filled with acid. The sleeve should be handled with gloves to avoid contaminating the quartz.

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12. Upgrade Your Irrigation System

By Paul Fisher and Robert Wick.

When it comes to water treatment, there are many options, which can make your choice confusing. You can potentially spend a lot of money up front or over time without reaching the desired outcome.

When choosing a specific water treatment method, you should first plan out a water treatment and sanitation *system*, rather than focusing on an individual technology. Determine your priorities, evaluate overall sanitation, describe and monitor your existing system, and only then choose which technologies best fit your needs (Table 12.1). In addressing these points, you will make better investment decisions.

What are your objectives and priorities?

What problems do you want to address with your water treatment system? If you don't know what you want to achieve, a salesperson might make that decision for you. You should specifically answer these questions:

- Which diseases do you want to control?
- How important is algae control?
- Are current or future regulations forcing you to eliminate or reduce runoff?
- Are there priority crops where the highest water quality is needed?

Table 12.1. Check list to determine your need for a water treatment system. The more questions you answer with a "YES", the greater the need for water treatment.

	YES	NO
Are you are recycling or plan to recycle irrigation water (enhancing pathogen dispersal)?	○	○
Is your water source a surface pond, river or lake (more likely to be contaminated with pathogens or algae than well or municipal water sources)?	○	○
Are your plants subirrigated (enhancing pathogen dispersal from one container to another especially if water is reused)?	○	○
Are you propagating cuttings or plugs (these are disease-sensitive crops with a high moisture level requirement)?	○	○
Is there an existing disease problem that can be spread by the irrigation system to other crops (corrective action is needed)?	○	○
Is there excess algae on greenhouse surfaces (suppression of algae is needed)?	○	○

Water treatment and sanitation

An irrigation system can distribute spores and other life stages of pathogens and algae from plant to plant. Some pathogens and algae can also grow and multiply on the surfaces of tanks and pipes, or in the water they contain. However, the irrigation system is only one source of contamination. Many growers have successfully subirrigated poinsettia crops or mist-propagated cuttings for years without disease issues by applying water as needed and practicing integrated pest management sanitation practices.

Understand the disease triangle

The disease triangle underlies management of disease pathogens. The pathogen must be introduced from some source, the environment must be favorable for its development and a host crop must be present (Figure 12.1).

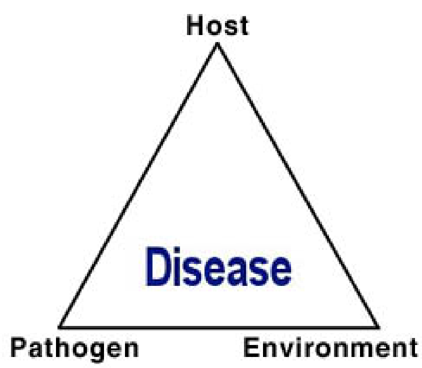

Figure 12.1. The disease triangle.

If an existing disease problem is present, do not jump to the conclusion that a water treatment technology is needed. Work with a plant pathologist to identify the source of the pathogen. For example, the source could be plant material (cuttings or plugs), reused containers, contaminated surfaces (benches or floors), insect vectors (thrips), dripping water from overhead baskets, growing medium (especially if it is reused), or the irrigation water (either the source or recycled water).

What aspects of the production environment can be improved that would address the disease triangle? For example, is a *Pythium* root problem in a poinsettia crop primarily caused by overwatering or should the growing medium be changed to one that has a greater porosity? If overwatering occurs and the cutting is contaminated, then all points in the disease triangle may still be favorable for *Pythium* to cause disease even if the spores in the irrigation water are killed.

Map water flow and treatment

On graph paper, make a diagram of how irrigation water flows through the greenhouse, with placement and specifics of tanks, filters and treatment systems including acidification. Water treatment system vendors need technical information about pipe lengths, diameters and flow rates to correctly size equipment. There have been cases where copper or ozone treatment systems were undersized for the volume of water in flood-floor greenhouses.

The irrigation map should identify points where contamination may occur in the system, including: the water source; mixing of return and fresh water; biofilm in pipes; organic material in collection tanks, on the floor and bench surfaces and plant material. In some cases, changing the water flow can solve an existing waterborne disease issue. For example, a tropical plant propagator was subirrigating liners from a tank that mixed fresh well water with return water from the crop. A problem with the waterborne fungal pathogen, *Ceratocystis fimbriata*, which attacks *Syngonium*, was addressed by adding a second tank that never received recirculated water. Only clean well water from the second tank was applied to the most disease-sensitive crops such as *Syngonium* (Figure 12.2).

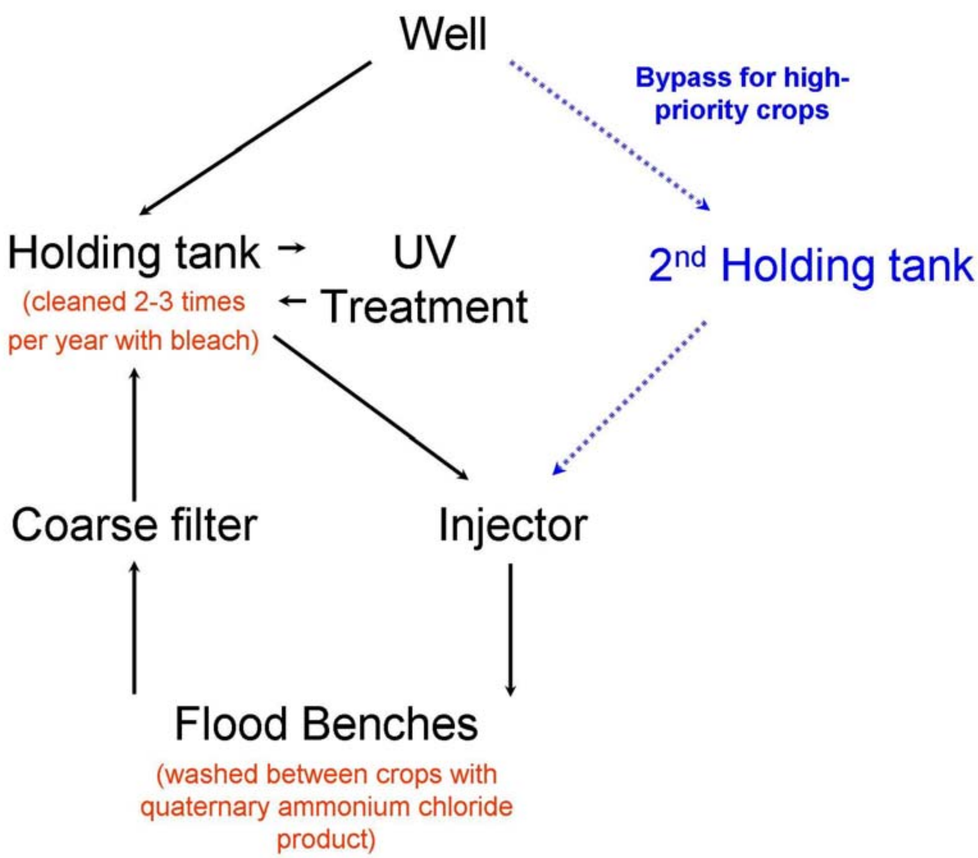

Figure 12.2. Two water circulation patterns from a tropical plant propagator. The existing flow pattern (shown in black) mixed fresh well water and return water in the holding tank. A new tank (blue) was added for crops that only received clean well water.

Sketching out a new system

If you are building a new facility, there is more flexibility available for the irrigation system. Make sure there are no dead zones in the plumbing that cannot be flushed out and cleaned, which is a common problem in older flood floor systems. If a complete system is being designed, some of the components that may be included are:

- Piping of different water qualities for low and high priority crops.
- A technology to sanitize recycled water. This typically involves filtration and a loop where portions of the return water are circulated through a residual or a point treatment such as ozone or ultraviolet light.
- A shock treatment, such as chlorine dioxide or activated peroxygen, for tanks and pipes.
- A surface treatment, such as a quaternary ammonium chloride product, for greenhouse floors and benches.
- A monitoring and control system for chemical, physical and biological aspects of water quality to ensure application of a safe and adequate level of sanitizing agent and adequate control of pathogens. This can include inline monitoring, onsite test kits and laboratory analyses.
- A chemical treatment (i.e., copper or chlorine) with residual activity for controlling pathogens and algae as water flows through irrigation pipes.

Monitor water quality

Three aspects of water quality affect crop quality and treatment options. Monitoring each of these provides a baseline and assists in engineering a new system. Make sure to follow laboratory guidelines when collecting and sending water samples to provide representative data.

Chemical water quality. Submit a sample from each water source to a lab for analysis of pH, alkalinity, electrical conductivity, nutrients and other salts (iron, aluminum, sodium and chlorine). All water treatment technologies are affected to some extent by water chemistry. For example, a water pH above 7.5 reduces efficacy of chlorine.

Physical water quality. Also request that the lab measure suspended solids and turbidity of water samples. The amount of suspended solids and organic matter in the water indicate how much additional filtration is required. It is also useful to note mesh sizes on existing filters, and how much sediment accumulates in places such as return tanks over time, and how often filters need to be cleaned. Turbidity affects light transmission, which is important for ultraviolet light treatment.

Biological water quality. Submit water samples from up to five different points in the irrigation system, including the water source(s), before and after existing water treatments, the outlet that is furthest from the water source, and the return tank or pond.

There are several biological tests that can be performed. At a minimum, request a presence/absence agar plate test of *Pythium*, *Phytophthora*, *Rhizoctonia* and *Fusarium* to the genus level (cost around $50-$150 per sample depending on the lab). If tests indicate positive for a potential pathogen, there are more detailed biological tests that can identify to the species level, but these are more expensive and mostly useful when a disease issue is showing up on a crop. These tests can help confirm where disease contamination is occurring in the irrigation system. One challenge with biological water tests is that they are highly variable, and sampling over time is therefore preferred. Another test that is useful for indicating biofilm build-up at different points in an irrigation system is a plate count for bacteria, fungus and algae measured in colony forming units (cfu) per volume of water.

Get advice

Water treatment is a specialist area, and it is worth consulting a range of technical sources. Consulting with irrigation engineers, other growers and university researchers may be helpful, in addition to communicating with vendors that represent different treatment technologies. A systems approach is required, many of the chemicals have some safety issues for workers and crops, there are regulatory restrictions, and each application needs to be individually engineered. This is rarely a case where a home-made solution is best. Visit the Water Education Alliance for Horticulture Web site (www.WaterEducationAlliance.org) to learn the latest information on water treatment, including upcoming workshops.

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