Greenhouse and Nursery Water Treatment Information System

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CHLORINATION

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Chlorination is a commonly used method of controlling pathogens in drinking water, and also is increasingly used in irrigation water treatment (Zheng et al, 2008). Pathogen control using chlorination involves the oxidation of organic material (including pathogens) by free (highly reactive) chlorine species (hypochlorous acid and hypochlorite ions). Hypochlorous acid is the stronger oxidizer and is most predominant in water with a pH between 6-7.5 (Zheng et al, 2008). With increasing irrigation water pH (alkalinity), the free chlorine species hypochlorous acid (HOCl) converts to hypochlorite (OCl^-), which is a much weaker oxidizer. These chlorine species may be added to irrigation water via water treatment with calcium hypochlorite [$Ca(OCl)_2$] or sodium hypochlorite (NaOCl), or by directly injecting chlorine gas into the water (Zheng et al, 2008).

The water property of "chlorine demand" is vital to take into consideration in order to supply adequate chlorine concentrations. Chlorine reacts with any organic substance in the irrigation water, and the "chlorine demand" is the amount of chlorine used up oxidizing materials (debris, algae, etc.) other than pathogens (Fisher, 2011). Because of chlorine demand, more chlorine must be added to the water initially than is required to kill a particular pathogen. As such, the concentrations in ppm listed in the next section do not reflect the amount of chlorine that should be supplied by the injection system. These values represent "residual chlorine", or the amount of chlorine available for pathogen destruction after chlorine demand has been satisfied. Residual chlorine is what must be measured to determine if chlorine concentrations are adequate for pathogen control (Zheng et al, 2008).

Application method

Calcium hypochlorite [$Ca(OCl)_2$] or sodium hypochlorite (NaOCl) (liquid bleach) react with water to form free hypochlorous acid and hypochlorite ions, which oxidize pathogens:

$$Ca(OCl)_2 + 2H_2O \text{ -> } 2HOCl + Ca^{+2} + OH^-$$

$$NaOCl + H_2O \text{ -> } HOCl + Na^+ + OH^-$$

For sodium hypochlorate, an injector is used to directly inject a liquid solution of concentration 5% to 15% chlorine into the irrigation water. The injector used must be resistant to corrosive chemicals, as well as having a high injection rate. Calcium hypochlorate typically comes in tablet form, which is dissolved in water using a chlorinator.

Critical Levels for Pathogens

The optimum range to treat common *Pythium* and *Phytophthora* spp. zoospores (common greenhouse and nursery pathogens) is 0.5 to 2.0 ppm free chlorine species. Refer to the below table for a detailed list of critical levels for potential plant and human pathogens.

Microorganism	**Pathogen Propagule**	**Critical Level (ppm)**	**Contact Time (min)**
Agrobcaterius tumefaciens	Bacteria	4.0	30.0
Campylobacter jejuni	Bacteria	0.1	5.0
Erwinia carotovora subsp. *Zeae* Sabet	Bacteria	1.0	1.0
Escherichia coli	Bacteria	2.0-3.0	45.0
Fusarium oxysporum	Conidia	14	6
Helicobacter pylori	Bacteria	1.1	45.0
Legionella pneumophila	Bacteria	3.3	0.0
Mycobacterium tuberculosis	Bacteria	1000.0	10.0
Pseudomonas aeruginosa	Bacteria	100.0	10.0
Staphylococcus aureus	Bacteria	100.0	10.0
Acanthamoeba castellanii	Protozoa	1.02	30.0
A. culbertsoni	Protozoa	1.25	30.0
Naegleria fowleri	Protozoa	0.74	30.0
N. gruberi	Protozoa	0.79	30.0
Bacillus subtilis	Endospores	100.0	60.0
B. anthracis	Spores	2.2	120.0
Plasmodiophora brassicae	Spores	2.0	5.0
Streptomyces griseus	Spores	0.79	1.5
S. griseus	Mycelia	0.96	2.5
Giardia lamblia	Cyst	1.5	10.0
Phytophthora capsici	Zoospores	1.0	2.0
P. cinnamomi	Zoospores	1.0	2.0
P. citicola	Zoospores	0.5	2.0
P. citrophthora	Zoospores	2.0	2.0
P. cryptogea	Zoospores	0.25	2.0
P. megasperma	Zoospores	1.0	2.0
P. nicotianae	Zoospores	0.5	0.5
Pythium aphanidermatum	Zoospores	2.0	3.0
Cucumber leaf spot virus (Stewart-Wade, 2011)	Virus	4	30
cucumber green mottle mosaic	Virus	>5	>120

virus (Stewart-Wade, 2011)			
Norwalk agent	Virus	10.0	30.0
Poliovirus 1	Virus	3.75	30.0
Rotavirus (human strain Wa)	Virus	3.75	30.0
Simian rotavirus SA11	Virus	0.5	4.0

This table is adopted from Zheng et al (2008). Please read that paper for more detailed information.

Critical Levels for Plants

Chlorine oxidizes all forms of organic matter, including living plant material. As such, when determining at what concentration to apply chlorination critical levels, the plants being produced must also be taken into consideration (Zheng et al, 2008). Growers produce numerous plant species, cultivars and varieties with varying sensitivity to chlorine. Dr. Zheng's lab at the University of Guelph has been conducting fairly extensive research on chlorine phytotoxicity (toxicity to plants), especially for container horticulture crops (Zheng et al, 2008; Cayanan et al, 2008; 2009). Below is a table with a list of critical levels for different plants. It is VERY IMPORTANT to note that the critical residual chlorine level is dependent on plant species and irrigation methods (e.g. overhead or root zone irrigation).

Plant Species	**Critical Level (ppm)**
Overhead irrigation	
Spiraea japonica	2.5[1]
Hydrangea paniculata	2.5[1]
Weigala florida	2.5[1]
Physocarpus opulifolius	5[1]
Salix integra	2.5[1]
Buxus microphylla	>2.4[2]
Chamaecyparis pisifera	>2.4[2]
Juniperus horizontalis	>2.4[2]
Picea glauca	>2.4[2]
Rhododendron catawbiense	>2.4[2]
Taxus media	>2.4[2]
Thuja occidentalis	>2.4[2]
Cornus alba	>2.4[2]
Euonymus fortunei	>2.4[2]
Hydrangea paniculata	~2.4[2]
Physocarpus opulifolius	~2.4[2]
Prunus x cistena	~2.4[2]
Salix integra	~2.4[2]
Spiraea japonica	>2.4[2]
Syringa meyeri	>2.4[2]
Viburnum x carlcephalum	>2.4[2]
Weigela florida	~2.4[2]
Root zone irrigation	

Gerbera	4 (Poncet et al., 2001)
Rose	4 (Poncet et al., 2001) > 0.4 (Nelson, 2003)
Unknown irrigation method	
Vegetable seedling	< 1 (Frink and Bugbee, 1987)
Begonia	> 2 (Frink and Bugbee, 1987)
Geranium	> 2 (Frink and Bugbee, 1987)
Pepper	> 8 (Frink and Bugbee, 1987)
Tomato	> 8 (Frink and Bugbee, 1987)
Kalanchoe	> 18 (Frink and Bugbee, 1987)
Lettuce	> 18 (Frink and Bugbee, 1987)
Tradescantia	> 18 (Frink and Bugbee, 1987)
Broccoli	> 37 (Frink and Bugbee, 1987)
Petunia	> 37 (Frink and Bugbee, 1987)
English ivy	> 77 (Frink and Bugbee, 1987)
Madagascar palm	> 77 (Frink and Bugbee, 1987)
Swedish ivy	> 77 (Frink and Bugbee, 1987)
Vegetables	≤ 2 (Brown, 1991)
Kentucky bluegrass sod	10 (Brown, 1991)
snapdragon	10 (Brown, 1991)
Impatiens	> 5 (Brown, 1991)
Marigold	> 5 (Brown, 1991)
Chrysanthemum	< 5 (Bridgen, 1986) > 0.4 (Nelson, 2003)
Zinnia	< 5 (Bridgen, 1986)
Zinnia seedling	> 7.6 (Bridgen, 1986)
Sweet pepper	> 50 (Ehret et al., 2001)

[1]*from Cayanan et al. (2008);* [2]*from Cayanan et al. (2009).*

Monitoring

If chlorine demand remained constant over time, determining the initial chlorine concentration required to get a desired residual concentration (0.5-2ppm) would only be a matter of using a chlorine meter to determine a constant ratio between the two. Unfortunately, chlorine demand of irrigation water and chlorine effectiveness does not remain constant and fluctuates based on water temperature, biological load, pH, and nitrogen content. Based on all these factors (which will vary continuously over time), supply will have to vary in order to maintain a constant residual concentration. Determining when and by how much to increase or decrease chlorine input will require close monitoring of residual chlorine levels and adjustment of input accordingly.

Residual chlorine levels should be monitored via a chlorine meter near the sprinkler, as by this point in the system chlorine will have reacted with any fertilizer or organic material present. This meter must measure free chlorine (types of chlorine available for pathogen destruction) as opposed to total chlorine (Zheng et al, 2008). It is best if meters are inline and connected to dosage systems, but handheld meters may also be purchased and used to take regular measurements. Chlorine meters typically cost around $150-$300 each, and can be purchased from any of the following manufacturers, among others:

Extech (http://www.extech.com/instruments/)
Hach (http://www.hachco.ca/)
Hanna (http://www.hannainst.com/)

Measurement of free chlorine can be combined with measurement of oxidative reductive potential (ORP) which can be measured using and ORP meter (inline or handheld). This meter measures the oxidizing strength of the chlorine present in the system (ie. its ability to destroy pathogens) and should be maintained above 700 mV (Fisher, 2011).

Safety considerations and handling information

Concentrated chlorine must not be mixed with other chemicals (ie. fertilizers or acids), and must only be mixed in the diluted levels present in the irrigation water (Fisher, 2011). Care must be taken when handling concentrated chlorine prior to injection, consult the MSDS sheet on these chlorine compounds for information on protection. Injectors and piping used to apply and transport chlorine must be made of materials that can tolerate caustic chemicals (Fisher, 2011).

To preserve its strength, calcium hypochlorite must be stored in a cool and dry location out of direct sunlight, in an airtight container made of dark glass or plastic (Zheng et al., 2008).

In combination with other technology

As additional organic matter in the irrigation solution will use up chlorine and therefore increase the amount of chlorine required for disinfection, water should be filtered before chlorination treatment to remove this excess organic matter. The filter size required will depend on the source of irrigation water (see information on pre-filtration). For example, water from a stationary water body such as a pond will contain more fine organic particles than municipal water, and as such will require a finer pre-filter to maximize chlorine effectiveness.

Cost for Technology:

The use of any water treatment technology is dependent on the size of the production facility and the amount of water used. Below are tables that summarize the average water consumption and cost of the technology of a small, medium and large facility. Remember: these costs are estimates, for exact pricing please contact the supplier.

Size of Production Facility	**Water Usage (litres/day) Greenhouse[1]**	**Water Usage (litres/day) Nursery[2]**
Small	29,263 – 37,857	700,993 – 2,103,001
Medium	33,560 – 134,244	1,401,997 – 3,219,732
Large	117,057 – 151,431	1,609,854 - 4,829,610

Size of Production Facility	Operation Cost Greenhouse (per day)[3]	Operation Cost Nursery (per day)[3,4]
Small	$13.53 – $17.50	$231 – $623
Medium	$15.52 – $57.55	$472 – $905
Large	$50.19 – $60.00	$476 – $1,358

[1]Flowers Canada Growers. (2011). Website: http://flowerscanadagrowers.com
[2]Canadian Nursery Landscape Association. (2011). Website: www.canadanursery.com/
[3]Chem Fresh, Inc. (2011). Website: http://www.chemfresh.com
[4.]Nurseries usually do not need to treat all their water, so nursery costs are likely overestimates.

Maintenance

Depending on the type of growing substrate used (inert vs. not inert), with continuous application of sodium hypochlorite, sodium (salt) and chlorine may eventually accumulate in growing media and nutrient solution, which may be detrimental to plants.

Required maintenance will include dismantling and cleaning the various components of the system. Cleaning will include the removal of iron and manganese deposits (EPA, 1999).

Pros and Cons

Pros:

- Relatively inexpensive installation and operating costs
- Effective
- Very commonly used, so information and technology is widely available
- Unlike some other chemical treatments (ozone, hydrogen peroxide) chlorine does not degrade quickly (has a long-lasting residual), and as such has a disinfecting effect for a long period of time

Cons:

- In recirculated irrigation systems, chlorine and sodium will eventually accumulate to levels that may be harmful to plants (van Os, 2010)
- Chlorine in its concentrated form is hazardous to nursery workers (Stewart-Wade, 2011).
- Corrosive (Stewart-Wade, 2011)

- Because of the by-products produced in chlorine treatment, it may be hazardous to release large amounts of chlorinated water (at the levels used in greenhouse and nursery pathogen control) to the environment. These by-products may also be potentially hazardous to workers (Stewart-Wade, 2011). Trihalomethanes, adsorbent organic halogens, chloroamines are all groups of potentially mutagenic or carcinogenic compounds produced by chlorination (Boorman et al, 1999; Stewart-Wade, 2011). It should be noted, however, that these compounds will not be present in any higher concentrations in greenhouse effluent water than they would be in typical treated municipal water.

- Effectiveness of chlorination is highly dependent on organic matter present in the irrigation solution (Fisher, 2011). As such, pre-filtration of irrigation water is required, which may be costly depending on the "dirtiness" of the water source used.

- The effectiveness of chlorine treatment is also highly dependent on irrigation water pH (optimal at 6-7.5)(Zheng et al., 2008). As such, pH must be maintained (may require adding acids at extra cost).

- The effectiveness of chlorine treatment is dependent on nitrogen compounds present in water (Zheng et al., 2008). Free chlorine reacts with ammonium to form chloramines and other combined chlorine compounds. These compounds are not as strongly biocidal as free chlorine. The interactions between chlorine and ammonium at varying concentrations of each are complex (Hong et al., 2003). While fluctuating nitrogen concentrations will require initial chlorine dosage be altered, as long as residual chlorine concentrations can be maintained, sufficient disinfection should be maintained.

- Because of the numerous factors causing fluctuations in residual chlorine, determining the amount of chlorine to be injected at a certain time to give sufficient residual chlorine may be complex, and require extra costs in the form of automated monitoring/control equipment (Fisher, 2011)

- Addition of sodium or calcium hypochlorite over time will raise water pH, which will reduce effectiveness of chlorination (Zheng et al., 2008)

- Solid calcium hypochlorate often contains impurities which may unexpectedly or detrimentally affect water composition (Zheng et al., 2008). Calcium hypochlorate may also crystallize, potentially causing the irrigation system to clog (Zheng et al., 2008)

Summary

Chlorination with sodium or calcium hypochlorate is an inexpensive, effective way of controlling a variety of greenhouse pathogens, which is especially important in greenhouses or nurseries recirculating irrigation water. Because of low costs, this water treatment method can be economical for a range of greenhouse and nursery operation sizes. One main issue with this technology is that chlorine will accumulate in systems that recirculate water. As such, effluent will need to be discharged more frequently than in recirculating systems using non-accumulating water treatment. As well, maintaining sufficient residual chlorine levels over time with fluctuating pH, organic matter, and nitrogen, may be a challenge and require costly monitoring and control equipment. Ultimately, though, inline monitoring and control equipment will reduce costs as it will prevent over or under application of chlorine which could cause damage to plants.

Suppliers

Some examples of suppliers of sodium and calcium hypochlorate include:

Producer	Product name	Producer website
Chem Fresh, Inc.	Oxcide	http://www.chemfresh.com/
Accu-Tab System	Accu-Tab Tablet	http://www.ppg.com/chemicals/accutab/pages/default.aspx

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