Greenhouse and Nursery Water Treatment Information System

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CHLORINE GAS

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Chlorine gas (Cl_2) is a poisonous, heavy gas that is soluble in water and is the cheapest form of chlorine to produce. It is a strong oxidizing agent that hydrolyzes readily in water, producing H^+ and Cl^- and free chlorine in the form of HOCl:

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

HOCl partially dissociates in water to form OCl^- and/or reacts with ammonia to produce combined chlorine. Special equipment and facilities are required for storage and use, and for prevention of corrosion. Chlorine gas is extremely dangerous to handle and government regulations must be followed for its use in North America.

Application method

Chlorine gas must be injected directly as it is highly toxic when released to the atmosphere. Chlorine gas is injected into the water using a venturi injector. Inside the venturi injector a vacuum is created. This is a safety feature and means that chlorine gas will only be injected into the solution when concentration in the solution is low enough that it will immediately dissolve.

Safety considerations and handling information

Gas chlorine has an advantage because it is contained in a closed cylinder where no mixing is required, in contrast to chlorine bleach which is held in mixing tanks. Accidental mixing of chlorine and fertilizer in a container is extremely dangerous, as it will create a thermo-reaction that can be explosive. The contact of fertilizer and chlorine after it has been injected into the system is not hazardous.

Due to its highly toxic nature special equipment and ventilation is needed when working with and handling contained chlorine gas. As well, if solution pH is allowed to become very low (below 4.0), chlorine gas may be released into the air (off-gassing), posing a safety hazard to workers (Fisher, 2011).

By-products produced by chlorine treatment (trihalomethanes, adsorbent organic halogens, and chloramines) can be hazardous to human health and the environment, including being potentially carcinogenic and mutagenic (Stewart-Wade, 2011).

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 page 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.

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 (Stewart-Wade, 2011)	Virus	>5	>120
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) has been fairly extensive. 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 depending 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).

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.

The installation of a chlorine gas system is high (up to $7000) (Fisher, 2011), but the operation cost is low. Below are tables that summarize the average water consumption and cost of the technology of a small, medium and large facility. Costs are based on assumption that $1 per pound of chlorine gas will treat 24,000 gallons of water (Fisher, 2011). 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)**	**Operation Cost Nursery (per day)[3]**
Small	$0.29 – $0.42	$7.72 – $23.15
Medium	$0.37 – $1.48	$15.43 – $35.44
Large	$1.29 – $1.67	$17.2 – $53.16

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

Maintenance

Because of the highly toxic nature of chlorine gas, it is crucial production and leak detection equipment be inspected regularly and receive routine maintenance, and records of these events kept. Specific maintenance requirements should be outlined by the manufacturer you purchase from and regulations in your area. Operation and maintenance requirements provided by the manufacturer should be followed exactly to prevent potentially disastrous error. Required maintenance will include dismantling and cleaning the various components of the system (the system must be shut down and thoroughly purged of chlorine gas beforehand). Cleaning will include the removal of iron and manganese deposits.

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
- Injection of chlorine gas will slightly lower solution pH. Over time, this will likely be beneficial as hypochlorous acid, (the most active/most effective form of free chlorine), is present in higher concentrations at a lower pH (Fisher, 2011).

Cons:

- Chlorine gas has higher installation costs than sodium or calcium hypochlorite. However, installation costs are not high compared to many other treatment technologies.
- Chlorine gas is highly toxic. Although current injection methods are aimed at ensuring safety, constant monitoring and upkeep of the injection system, as well as knowledge of emergency procedures, are crucial
- Corrosive (Stewart-Wade, 2011)
- In recirculated irrigation systems, chlorine and sodium will eventually accumulate to levels that may be harmful to plants
- 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. 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), and nitrogen compounds in water (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

Summary

Like chlorination with sodium or calcium hypochlorate, chlorine gas injection is a relatively inexpensive, effective way of controlling a variety of greenhouse pathogens, which is especially important in greenhouses or nurseries recirculating irrigation water. Because of low operating costs, this water treatment method can be economical for a range of greenhouse and nursery operation sizes. However, 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 chlorine gas systems include:

Producer	Product name	Producer website
Regal Chlorinators Inc.		http://www.regalchlorinators.com

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