Greenhouse and Nursery Water Treatment Information System

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CHLORINE DIOXIDE

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Background

Chlorine dioxide is a strong disinfectant that is 25 times more effective than chlorine gas and is effective at a wide pH range (4-10). It is commonly used to remove biofilm in irrigation systems and clogged emitters.

Like other chemical water treatment methods chlorine dioxide disinfects irrigation water by oxidizing and destroying the cell walls and organelles of pathogens. However, the means by which chlorine dioxide oxidizes pathogens differs from that of other chlorine compounds. Instead of forming the oxidizer hypochlorous acid in solution, chlorine dioxide exists as a (dissolved) gas in water, with allows it to have greater oxidizing strength than other chlorine compounds:

$$HOCl + HCl + 2NaClO_2 > 2ClO_2 + 2NaCl + H_2O$$

Because of its oxidizing power, chlorine dioxide is often used as a shock treatment at high concentrations to remove biofilms. Alternatively, like other chemical treatments it may be applied continuously in lower concentrations in greenhouse areas highly susceptible to disease.

Shock treatment is recommended twice a year and usually requires a concentration of 20-50ppm chlorine dioxide be maintained for 12 hours, and then the irrigation system thoroughly rinsed before irrigation begins again, due to risk of phytotoxic effects with high concentrations. After shock treatment, a continuous treatment of 0.25ppm residual chlorine dioxide is usually sufficient to prevent regrowth of biofilm.

Please read Fisher (2011) and Zheng et al (2008) for more details.

Application method

Chlorine dioxide is unstable and explosive in its gas state. Thus, it cannot be stored effectively in gas form and liquid (already dissolved) chlorine dioxide often has to be produced on-site in an automated generator and injected into the irrigation water. However, chlorine dioxide may also now be purchased as tablets/powder which can be dissolved in a storage tank of water to form a concentrated solution. This solution may then be injected into the irrigation system. While this method gets rid of the need for specialty equipment and thus reduces installation costs, it also has higher operation costs as the operator must pay continually for tablets (Fisher, 2011). As such, both systems have their pros and cons. Tablet/powder chlorine dioxide is likely best suited to applying chlorine dioxide infrequently in high concentrations (shock treatment to remove biofilm). Alternatively, for continuous application at low doses, installation of a chlorine dioxide production system may be more cost effective.

"Purity" of the chlorine dioxide solution produced will also vary based on the means by which it is generated. Typical generators that use sodium chlorite and hydrochloric acid to produce chlorine dioxide tend to produce solutions that are 80% pure, with the rest being potentially toxic by-products (EPA, 1999). Tablet/powder forms of chlorine dioxide which produce a solution of >99% purity are available. These aspects may need to be taken into consideration if you are concerned about minimizing by-products.

Safety and handling information

Toxic off-gassing (release of gas from solution) has been reported to occur at water temperatures above 27ºC (Fisher, 2011). As such, it is advised that water temperature is maintained below 21ºC (Fisher, 2011). An enclosed irrigation system should be used as this will also help to keep chlorine dioxide in solution.

Critical Levels for Pathogens

The optimum chlorine dioxide range to treat biofilms and common plant pathogens is 0.25 to 3.3 ppm (Fisher, 2011). Refer to the below table for a list of critical levels for different pathogens.

Microorganism	Pathogen Propagule	Critical Level (ppm)	Contact Time (min)
Algae (Konjoian, 2011) (Rav-Acha et al., 1995)	N/A	 0.25-0.50 2	 Continuous5- 10
Alternaria zinniae (Beardsell et al., 1996)	Spores	2 (tap water) 3.1 (dam water)	12 8
Botrytis cinerea (Roberts and Reymon, 1994)	Conidia/Sporangiospores	3	1
Biofilm (Fisher, 2011)	N/A	0.25	Continuous
Colletotrichum capsici (Mebalds et al., 1996)	Conidia	0.7 (tap water) 1.8 (dam water)	2 2
Cryptosporiopsis perennans (Roberts and Reymon, 1994)	Conidia/Sporangiospores	1	0.5
Cylindrocladium sp.	Conidia	10	0.5

(DPI, 2007)			
Erwinia chrysanthemi (Wick, 2010)	Bacteria	20	20-40
Fusarium oxysporum (Mebalds et al., 1995) (Chastagner and Riley 2002) (Copes et al., 2004) (Wick, 2010)	Conidia	0.4 (tap water) 1.0 (dam water) 2.5 (44ºC water) >0.8 (water with N and metals) 5	2 2 5 0.5 20
Mucor piriformis (Roberts and Reymon, 1994)	Conidia/Sporangiospores	1	2
Penicillium expansum (Roberts and Reymon, 1994)	Conidia/Sporangiospores	1	2
Phytophthora cinnamomi (Mebalds, 1995) (Beardsell, 1996)	Spores	1.0 (tap water) 2.6 (dam water) 2.9 (dam water)	2 2 4-8
Pythium ultimum (Mebalds, 1996) (Beardsell, 1996) (Wick, 2010)	Spores	3.6 (tap water) 0.5 (tap water) 2.4 (dam water) 1 (distilled water)	2 2 2 5
Ralstonia solanacearum (Yao et al. 2010) (Elphinstone and Harris, 2002)	Bacteria	1.3 0.1	N/A 2
Rhizoctonia sp. (DPI, 2007)	Mycelia	Ineffective	
Thielaviopsis basicola (Copes et al., 2004)	Conidia	>0.9 (water with N and metals)	0.5
Xanthomonas campestris (Krathausen et al., 2011)	Bacteria	0.21	daily

[N/A] Not Available

Critical Levels for Plants

Growers produce numerous plant species, cultivars and varieties with varying sensitivity to chlorine dioxide. There is very little data on phytotoxicity levels for chlorine dioxide. Below is a table with a list of critical levels for the few plants that have been researched.

Plants	Critical Level (ppm)
Impatiens foliage	1-2
Geranium foliage	1-2
Radish Seedlings	0.52
Lettuce Seedlings	0.52

Adopted from Carrillo et al. 1996 and Fisher 2011.

Generally, it is advised that plants not be exposed to chlorine dioxide levels higher than 0.25 ppm (Fisher, 2011). It is recommended, as with any water treatment method, that the producer perform a phytotoxicity test on a small group of plants under simulated production conditions prior to widespread application. This is particularly important for chlorine dioxide due to the lack of information on phytotoxicity

Monitoring

Chlorine dioxide test strips or meters are available. For most accurate monitoring of chlorine dioxide levels an inline meter should be used. The value that should be monitored is residual chlorine dioxide. Residual chlorine dioxide levels should be monitored via a chlorine meter near the sprinkler, as by this point in the system chlorine dioxide will have reacted with any fertilizer or organic material present (Hong et al., 2003).

Measurement of residual chlorine dioxide 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 dioxide present in the system (ie. its ability to destroy pathogens) and should be maintained above 700 mV (Fisher, 2011).

In combination with other technology

Like other oxidizers, chlorine dioxide oxidizes any organic matter it comes in contact with), although chlorine dioxide concentration is much less affected by organic matter load than other chlorine compounds (Van Os, 2010). Regardless, organic particles and other oxidizable material should be filtered from irrigation water before treatment with chlorine dioxide to increase disinfection efficiency.

Cost for Technology

Chlorine dioxide is effective in disinfecting irrigation water and systems, but may be costly for growers that use a large volume of water. Many growers will focus the use of chlorine dioxide in smaller areas with highly diseases-sensitive plants.

Capital costs of a chlorine dioxide dosing system are +$18,000. The operating cost 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 operating cost of the technology of a small, medium and large facility. These prices are based on a dosing rate of 0.5ppm, but a greater rate may be required depending on the organic content of the water.

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	$0.50-2.50	$12+
Medium	$0.55-5.50	$23+
Large	$2.00-6.25	$27+

[1]Flowers Canada Growers. (2011). Website: http://flowerscanadagrowers.com
[2]Canadian Nursery Landscape Association. (2011). Website: www.canadanursery.com/
[3]Ranges have been estimated from a survey of companies and are only intended to give a rough idea of cost. To determine exact costs for your system, please contact a supplier.
[4]Nurseries usually do not need to treat all their water, so nursery costs are likely overestimates.

Conversely, capital costs for chlorine dioxide in tablet form are very low, but operating costs are higher (>1.50/m^3).

Pros and Cons

Pros:

- Unlike other chemical disinfection methods, chlorine dioxide is effective over a wide pH range (4-10) as it remains chemically unchanged over this range (Van Os, 2010)
- Also unlike other chlorine compounds, chlorine dioxide does not react with nitrogen and as such its biocidal properties are retained in presence of fluctuating nitrogen levels (Stewart-Wade, 2011).
- Effective even when irrigation solution has higher organic load (Van Os, 2010). However, pre-filtration is still advised

Cons:

- Currently very little phytotoxicity information available
- Slightly more expensive than other methods of chlorination
- Often requires costly, specialized equipment

Summary

Chlorine dioxide is a more powerful oxidizer than other chlorination treatments, and is effective at controlling a range of greenhouse pathogens independent of pH fluctuations. It also serves to keep irrigation systems free of biofilm and algae. Because of its high effectiveness as an oxidizer, but slightly higher cost than other chlorine treatment methods, chlorine dioxide is often applied in very high concentrations as a shock treatment to remove biofilm, or applied in continuous treatment at very low concentrations. It is usually continuously applied to crops or areas of the greenhouse particularly susceptible to disease. Especially for nursery operations, use of chlorine dioxide treated water over a large area can become expensive.

With the introduction of a tablet form of chlorine dioxide, the problems that came with the need for on-site production have been somewhat relieved. Possibly the current main issue with chlorine dioxide is the lack of information on phytotoxicity. Like many other chemical treatment methods, information on chlorine dioxide levels toxic to pathogens needs to be expanded to bacteria and nematodes, as well as more fungal species (Stewart-Wade, 2011).

Suppliers

Some examples of suppliers of chlorine dioxide disinfection technology include:

Producer	Product name	Producer website
ProMinent	Varied (injector systems)	http://www.prominent.ca/Products/Disinfection-and-Oxidation-Systems/Chlorine-Dioxide-Systems.aspx
Selective Micro Technologies	Selectrocide (tablet form)	http://www.qwatro.com/selectrocide.php
AquaPulse Systems	APS Dioxide (injector system)	http://www.aquapulsesystems.com/
Siemens	Varied (injector systems)	http://www.water.siemens.com/en/products/chemical_feed_disinfection/chlorine_dioxide_generation/Pages/default.aspx

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