Greenhouse and Nursery Water Treatment Information System

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OZONATION

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Background

Ozone (O_3) consists of three oxygen atoms and inactivates microorganisms by oxidizing the cell membrane, enzymes, proteins, DNA and RNA. Of all chemical treatments available, ozone is the strongest oxidizer. In addition to being a strong oxidizer itself, ozone decomposes rapidly in water, forming hydroxyl radicals that serve as even stronger oxidizers that may destroy more recalcitrant contaminants. The eventual end product of ozone decomposition is oxygen, meaning ozone treatment does not produce any toxic residuals, and can even provide oxygen to the root system.

Application method

Use of ozone for water treatment requires the purchase and installation of an ozone production system. In medium to large-scale facilities a corona discharge ozone generator is often used to convert oxygen gas to ozone. Oxygen gas is passed through an electrical field that splits the oxygen molecules (O_2) into oxygen atoms (O^-). O^- atoms stabilize by bonding with other O_2 molecules to form ozone (O_3). The ozone produced is then injected into a pressurized system using a venturi injector. Other injection/mass transfer systems such as static mixers or bubble columns may also be used.

Ozone generators that use ultraviolet light to generate ozone from oxygen are also available. However, ozone production from these systems is much lower than that of corona discharge systems (1% wt compared to 10% weight). These systems are comparatively simple and may be useful for small-scale systems.

Newer technology also includes the electrochemical ozone generator. In this system (of which there are 2 types), electrolysis is used to generate ozone from the water itself. Electrochemical generators can produce very high ozone concentrations (3-47%), although high purity water input is required. Because it is such a new technology, the commercial reliability of the electrochemical generator remains to be established.

Ozone may be injected into the nutrient solution at one point in the irrigation system and then removed from water prior to reaching the crop, or it may be left in solution to treat pathogens in the root zone. Often the second method is used, due to the previous lack of information on phytotoxicity of aqueous ozone. However, leaving ozone in solution is useful for cleaning the entire system of biofilm and preventing pathogen proliferation at the plant (not just preventing it from spreading) (Graham, 2012). With an increasing number of studies showing lower levels of aqueous ozone are not harmful to plants, leaving ozone in solution may be feasible (Graham, 2012).

Safety and handling information

Ozone is highly corrosive due to it being a very strong oxidizer. As such, the only materials coming in contact with high levels of ozone should be those provided with the ozone production system, which are made from specialized oxidation resistant materials such as Stainless steel (300 series), Kalrez®, Kynar®, Teflon and Viton®.

Gaseous ozone is considered a pollutant and is harmful to human and phytotoxic to plants when the concentration reached certain levels (Zheng et al, 2000). Properly operating ozone generators will pose little risk to workers. However, failures are always a possibility. As such, measures should be taken to minimize ozone release to the air in the event of a leak. Ambient ozone gas monitors should be installed to trigger shutdown of generators. Dissolved ozone is not considered harmful to the environment or human consumption, and as such there are no restrictions on the release of ozone-treated water (Stewart-Wade, 2011).

Regardless of the generator or injector used, some ozone will fail to transfer into solution. Alternatively, gaseous ozone may be released from solution (off-gassing). This gaseous ozone may be destroyed using heat, UV, a granulated activated carbon bed, or manganese dioxide catalysts. However, if ozone is not removed from the nutrient solution prior to application to plants, off-gassing from water coming from the sprinkler head (with phytotoxic effects such as foliar damage) can still be a major problem in systems using overhead irrigation (Zheng et al. 2000).

Critical Levels for Pathogens

Ozonation appears to be effective at controlling a number of common greenhouse pathogens at relatively low doses. Refer to the below table for a list of critical residual levels for common plant pathogens.

Microorganism	Pathogen Propagule	Critical Level (ppm)	Exposure Time (min)
Algae (Newman, 2004)	N/A	0.01-0.05	N/A
Alternaria zinniae (limited ctrl) (Beardsell et al., 1996)	Spores	0.7	16
Biofilm (Newman, 2004)	N/A	0.2	30
Fusarium oxysporum (Igura et al., 2004) (Beardsell et al., 1996) (Beardsell et al., 1996)	Conidia	 0.6 1.6 (tap water) 1.1 (dam water)	 3 2 4
Phytophthora capsici (McDonald, 2007)	Chlamydospores	1.5	23
Phytopthora cinnamomi (Beardsell et al., 1996)	Chlamydospores	0.8 (tap water) >1 (dam water)	8 4
Pythium aphanidermatum(Graham et al., 2012)	Zoospores	<2	N/A
Pythium ultimum (Beardsell et al., 1996)	Zoospores	1.2 (tap water) 0.8 (dam water)	2 4

N/A Not Available

Critical Levels for Plants

Growers produce numerous plant species, cultivars and varieties with varying sensitivity to ozone. Below is a table with a list of critical levels for different plants.

Plants	Critical Level (ppm)
Spiraea japonica	1.5 (Graham et al., 2009)
Hydrangea paniculata	1.5 (Graham et al., 2009)
Weigela florida	1.5 (Graham et al., 2009)
Physocarpus opulifolius	1.5 (Graham et al., 2009)

Salix integra	1.5 (Graham et al., 2009)
Tomato in rockwool (Graham et al., 2012)	3.0
Chrysanthemum (McDonald, 2007)	No effect at 1.5

As all of the studies in the table above were performed using drip or overhead irrigation, phytotoxicity in sub-irrigation systems is not known. However, it is likely that tolerance would be lower in these systems, as ozone solution would be directly in contact with the root for extended periods of time, and there is also a possibility of off-gassing damage.

Monitoring

Monitoring of residual ozone levels is difficult due to the rapid rate at which ozone degrades and is used up in water. Dissolved ozone readings are also very sensitive to changes in water pressure. Inline monitors (monitors measuring levels within the irrigation line) are the most accurate method of measuring dissolved ozone levels. Different types of continuous/in-line measurement devices are available. Electrochemical membrane electrodes measure a current between two electrodes that is proportional to the concentration of ozone in solution (Gottschalk et al., 2000). These systems, which cost from $2,500-$8,000 provide rapid and continuous measurements and are preferred for larger facilities. Aqueous ozone (or gas ozone) can also be continuously monitored using UV absorption. UV radiation around 254nm is introduced into a sample stream of water, and decrease in intensity is proportional to ozone concentration in the water (although interfering compounds must be compensated for) (Gottschalk et al., 2000). This system costs from $5,500-8,000.

Often, an ozone monitor is provided along with the installed system. In this case, the ozone monitor is likely to be connected to a controller, so that ozone dosage may be altered in response to measured residual levels. Generally, these types of ozone monitors are quite costly.

Meters measuring oxidation-reduction potential, although much less expensive, cannot measure ozone levels in irrigation water very precisely due to non-selectivity.

In combination with other technology

As with other chemical treatment methods that rely on oxidation, irrigation water should be filtered before ozonation. This removes particulate organic matter that would otherwise react with and take up ozone, lessening the amount of ozone available for oxidation of pathogens. Ozone treatment is often combined with UV technology, as ozone may provide a residual (long-lasting) sanitation effect not provided by UV, which can serve to keep the irrigation system clean along the entire length of the system. Combining UV with ozone is especially effective (compared to combining UV with other chemical treatments) as when UV light reacts with an oxidizer such as ozone (or hydrogen peroxide) it creates hydroxyl radicals, which are highly active oxidizers and more effective for sanitation than ozone itself (Fisher, 2011). However, this may ultimately be very costly, as both ozone and UV water treatment require costly, specialized equipment.

Combining ozone and hydrogen peroxide application (peroxone treatment) may also result in improved disinfection (EPA, 1999). The mechanics of this treatment are similar to those of combining UV-hydrogen peroxide treatment. Mixing hydrogen peroxide and ozone together in solution accelerates the decomposition rate of both (EPA, 1999). When these compounds decompose they produce the stronger-oxidizing hydroxyl radicals. By increasing decomposition rate, more hydroxyl radicals are present in solution at a certain time, and greater oxidation/disinfection can take place. To maximize disinfection potential, ozone should be added to the irrigation solution before the addition of hydrogen peroxide. Langlais et al. (2001) combined these treatment methods and successfully controlled various greenhouse pathogens using below-phytotoxic levels of hydrogen peroxide. At the same time, the beneficial microbial population of the growth media was maintained. However, because hydroxyl radicals degrade so quickly, monitoring residual levels is currently not feasible (EPA, 1999).

Costs

The use of any water treatment technology is dependent on the size of the production facility and the amount of water used. Capital costs for the ozone system are 12,000+, depending on the amount of water that must be treated. Daily operating costs for facilities of different sizes, based on the average water consumption of these facilities, are shown in the tables below.

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	Operation Cost

	Greenhouse (per day)[3]	Nursery (per day)
Small	$0.80-2.00	No data
Medium	$0.80-2.75	No data
Large	$1.20-2.75	No data

[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.

Pros and cons

Pros:

- Ozone that does not react with contaminants will degrade to oxygen, providing increased oxygen to plant roots. This may slightly improve plant performance (Zheng, 2007)
- Dissolved ozone in effluent does not pose any environmental hazards as it degrades rapidly to oxygen
- Ozone also reacts with and degrades pesticides, which helps prevent accumulation of pesticides to phytotoxic levels in recirculating irrigation water (Stewart-Wade, 2011)
- Will not leave a chemical residue on produce/crop

Cons:

- The degradation rate of ozone (and thus the amount of time it will remain in water to disinfect) is not only rapid but varies in response to pH and temperature. As such, low pH and temperature must be maintained to optimize longevity and resultantly disinfection ability of ozone (Fisher, 2011; Farooq et al., 1977)
- Reacts with, and is used up by, organic matter, iron (depending on the chelate used: use of EEDHA reduces efficacy while DTPA and EDTA do not (Vanachter et al., 1988)), manganese (also depending on chelates), nitrates, and bicarbonate (Stewart-Wade, 2011)
- Like many other chemical treatments, as ozone reacts with organic matter, pre-filtration of the irrigation solution is required
- Due to reaction of iron, higher iron input may be needed to meet plant needs and buildup of iron deposits may need to be dealt with
- Risk of phytotoxic off-gassing (particularly in overhead irrigation systems)

- Possibly the greatest disadvantage is the complexity and high cost of the production system and monitoring equipment, which may make this method infeasible for larger production facilities

Summary

Overall, ozone is an established and reliable irrigation water treatment technology. It is proven that ozone can control a number of common pathogens with apparently little potential for phytotoxic effects at lower levels. However, further information on phytotoxicity in subirrigation hydroponic systems is required. The complex equipment required and high cost mean that use is limited to those who can afford initial start-up costs. Because of the low operation cost but high start-up cost, ozone treatment may be best suited to larger greenhouse operations treating large amounts of water. Nevertheless, smaller systems will be less costly, and may still be affordable to small operations.

Suppliers

Some examples of manufacturers or suppliers of ozonation technologies include:

Producer	**Product name**	**Producer website**
Ozmotics	Varied	http://www.ozmotics.com/default.aspx
ProMinent	Varied	http://www.prominent.ca/Home.aspx
TrueLeaf	In-line and batch treatment systems	http://trueleaf.net
Dramm		http://www.dramm.com/html/main.isx?sub=503

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