W 920-B

Bridging the GAPs: Approaches for Treating Water On-Farm

Agricultural Water Treatment Tools

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Bridging the GAPs: Approaches for Treating Irrigation Water On-Farm

The goal of this series of modules on water treatment is to equip growers with the knowledge to successfully implement water treatment systems on their farms. Fruit and vegetable growers are continually assessing their operations to determine where they can limit risk and increase productivity. As a result, many have expressed interest in learning more about how on-farm preharvest water treatment systems work and how they may fit within their current setup.
These four modules help growers to: 1) understand the background for water treatment; 2) learn about different approaches to treating water on-farm; 3) how to implement these systems to meet requirements of the Produce Safety Rule; and 4) how to verify that the system is operating as intended.

W 920-A, Agricultural Water Treatment and FSMA
W 920-B, Agricultural Water Treatment Tools
W 920-C, Developing On-farm Agricultural Water Treatment Programs
W 920-D, Implementing Agricultural Water Treatments on the Farm


Agricultural Water
Treatment Tools
Module 2

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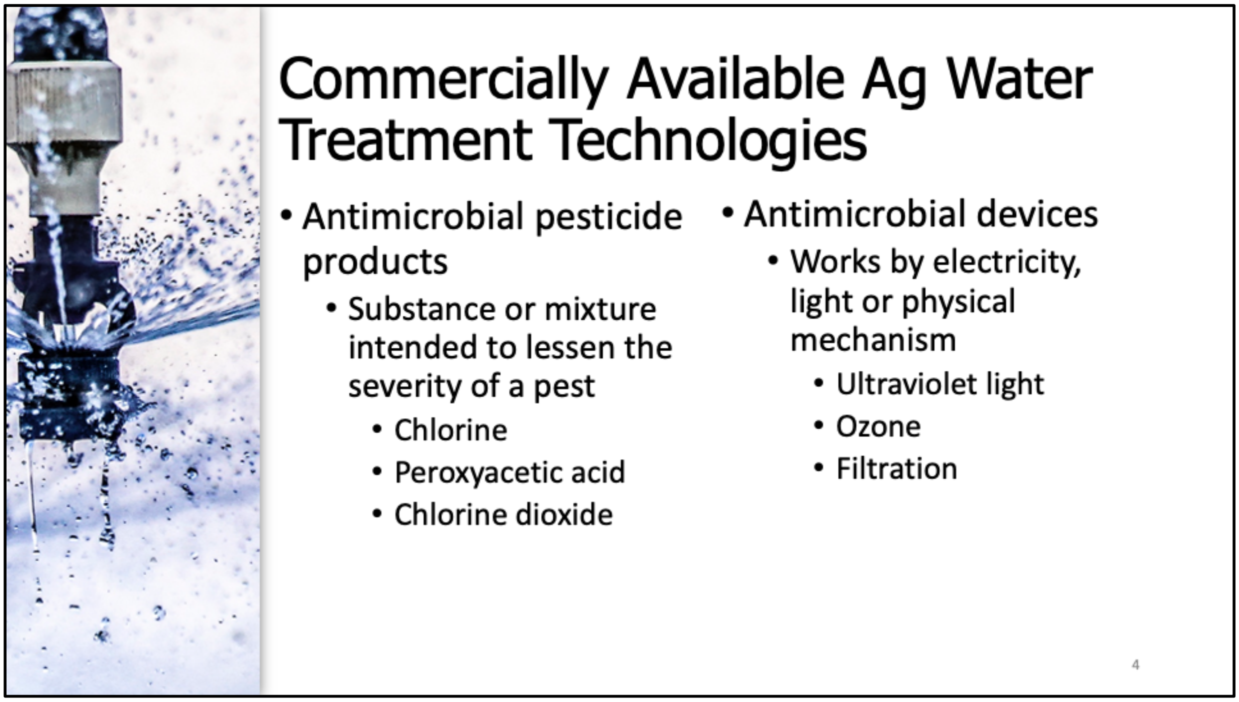
Learning Objectives

1. Contrast the differences between water treatment systems

2. Justify what treatment system(s) would work best on your farm

Once it has been determined that irrigation water mitigation must be provided, the next step is to determine the mitigation method. There are many options for irrigation water treatment. We can choose between disinfectant chemistries (chlorine for example) or disinfectant devices (UV light for example). And, even within the two groups, there are additional options. It is important to remember that there is no “one size fits all” selection. Our objective in this session is to present the most common methods used to provide disinfection and discuss the advantages and disadvantages of each. Ultimately, the grower needs to make a decision as to the technology that is best for their operation.



Good Opportunity to reinforce FSMA terminology about mitigation products and devices

Pesticide Product - contains a substance or mixture of substances that is intended to destroy, repel, prevent or mitigate (lessen the severity of) a pest. This includes substances that attract pests to lessen their impact, for example by attracting pests to a trap.

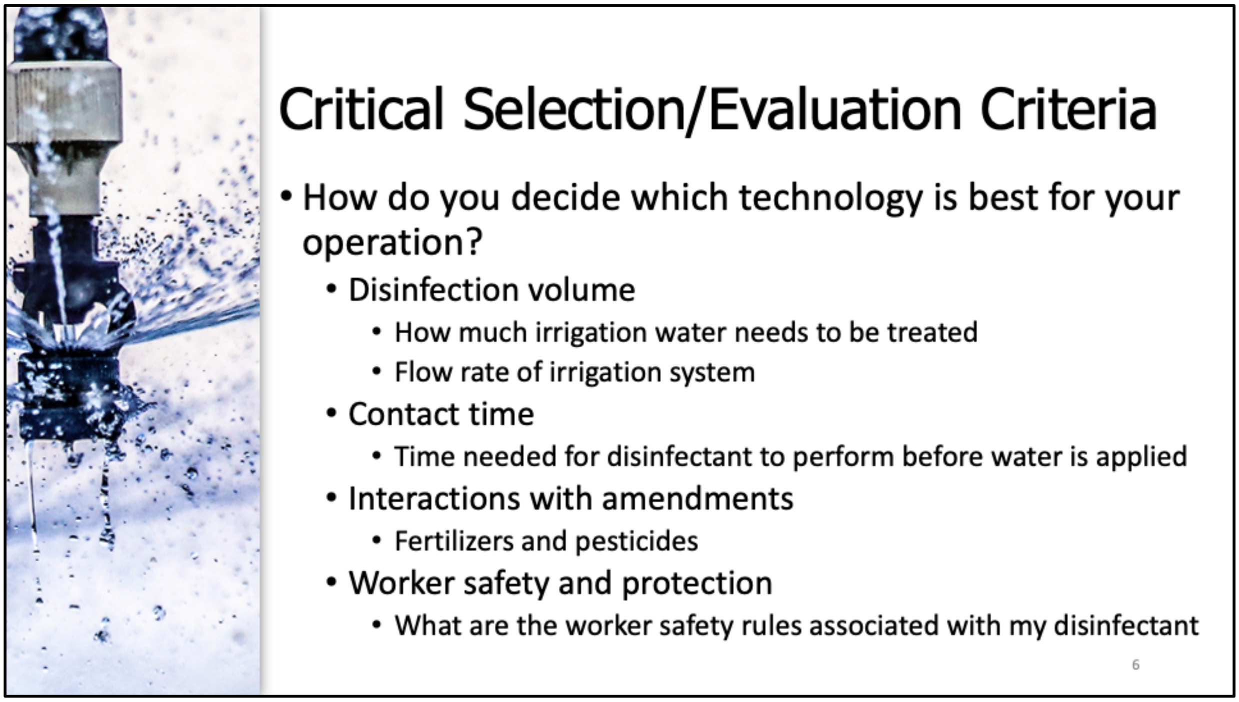
How Regulated: Must be registered unless it qualifies for an exemption.

Pesticide Device - works by physical means (such as electricity, light or mechanics) and does not contain a substance or mixture of substances to perform its intended pesticidal purpose.

How Regulated: We do not require registration for these. However, these devices are regulated in that "false or misleading claims" cannot be made about the effectiveness of devices. If a manufacturer is making claims about a device, they should have scientific data to back up the claims.

Some devices are not regulated. For example, any device that depends more upon the performance of the user than the performance of the device itself to be effective (such as a fly swatter) is not regulated. Also, traps for vertebrate animals are not regulated.

Growers may be used to using sanitizer products like this, to prevent emitter clogging by microbial biofilms.



Critical Selection/Evaluation Criteria
Use this slide as an introduction to how we might evaluate which disinfection technology is best for the operation. Discuss issues such as how big is the production operation, how many water sources are used, who will be operating the disinfection system.

Disinfection Volume:
Irrigation volume: Does the irrigation system apply acre-inches or acre-feet of water? Two inches per week over 10 acres is 543,000 gallons per week (one acre-inch is 27,156 gallons). If you are going to apply 20 ppm of Active Ingredient chlorine, you have to add 133 pounds of Ca(ClO)2 per week.

Irrigation Flow Rate: What is the flow rate of the irrigation system? If it applies water at 200 gallons per minute, your injection system needs to add Ca(ClO)2 at approximately 23 grams per minute.

Contact time: the amount of time the disinfectant needs to contact the target microorganism to inactivate it. Contact time can be the time the water is exposed to UV, of how long water and chlorine are in the irrigation distribution pipe before the water contacts the crop.

Interaction with Amendments: If using fertigation or chemigation, will the disinfectant react with the fertilizer or pesticide?

Worker Safety and Protection: Disinfecting the human being can result in painful disfigurement and/or death. What degree of worker competence is available to operate the equipment? What type of worker safety training is required?

Antimicrobial Pesticide Products

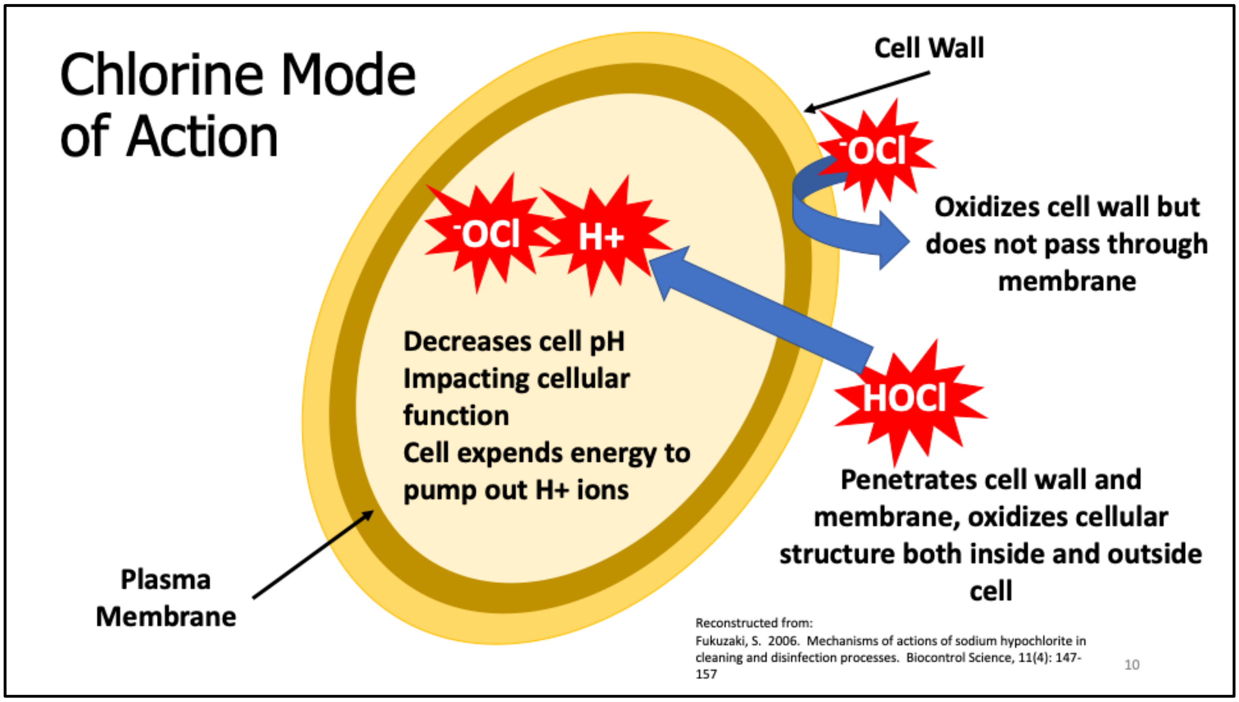
Chlorination (HOCl)

- Usually, when you hear someone use the term chlorination, they're usually referring to HOCl or hypochlorous acid
  - This is the most active form of chlorine for disinfection
  - Hypochlorous acid forms as chlorine reacts with water
- Chlorine is a very common disinfectant and is:
  - Relatively inexpensive
  - Very effective
  - Available in several forms
    - Powders
    - Liquids
    - Gas

We will start with chlorine – we have a long history of using chlorine to disinfect drinking water. The word chlorination is often (but incorrectly) used synonymously with disinfection.

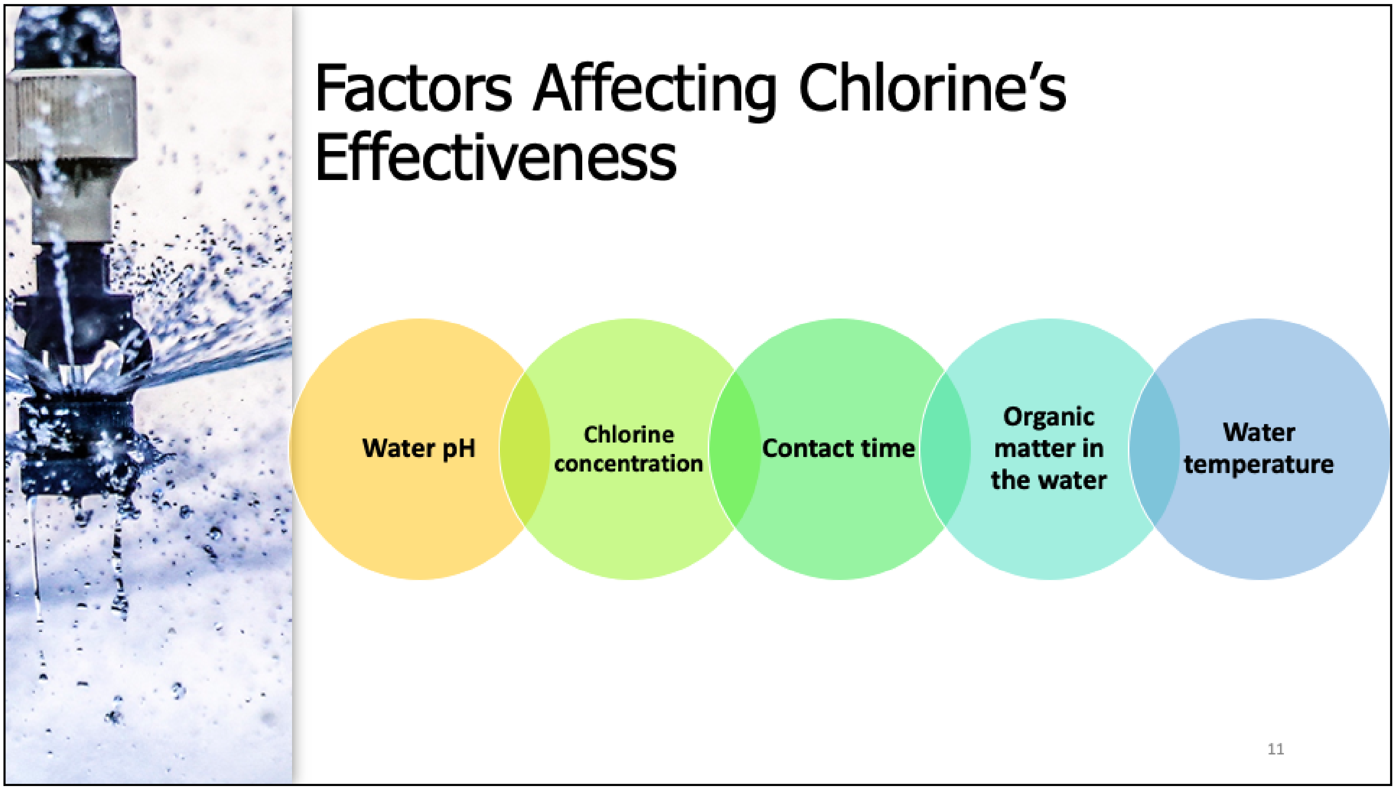
The germicidal form of chlorine is HOCl or hypochlorous acid, as shown in the next slide, the compound forms as chlorine reacts with water.

Chlorine is relatively inexpensive and widely available.

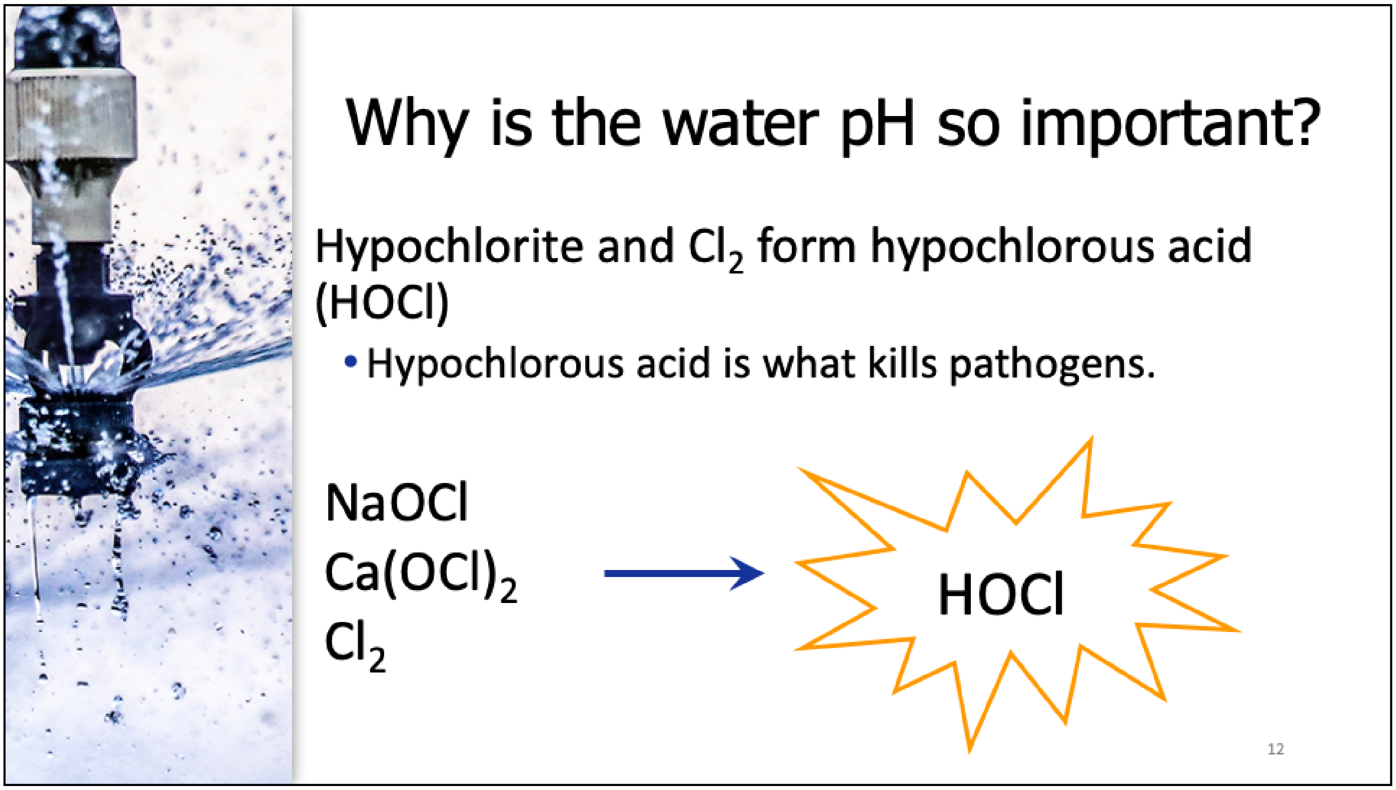


Mode of Action
HOCl is a neutral species and can more easily penetrate the cell wall and the membrane. Once inside the cell, it can oxidize various components with cell – such as the mitochondrion, which is the powerhouse of the cell. Just a few hits of HOCl will inactivate the cell.

OCl has a negative charge and be repelled by the membrane, but OCl will oxidize components of the cell wall. This creates significant damage, but it takes many more "hits" before the sufficient damage is done that would inactivate the cell.



If you choose to "learn" chlorine, then you must understand the limitations and the challenges. We will discuss how pH, chlorine concentration, contact time, organic matter (as it relates to chlorine demand) and water temperature can affect the rate and completeness of chlorine disinfection.



When sodium hypochlorite is added to water, it forms sodium hydroxide (NaOH) and hypochlorous acid (HOCl). All three forms of chlorine produce hypochlorous acid (also called available chlorine or active chlorine).
Hypochlorous acid is what kills pathogens.
"The mode of action appears to be that hypochlorous **acid permeates bacterial cells and oxidizes sulfhydryl groups on amino acids of proteins** (Knox et al., 1948). Proteins essential for enzymatic activity are irreparably damaged and bacterial cell function is diminished. When damage is severe enough, the bacterial cell dies."

Switch from effective to not so effective

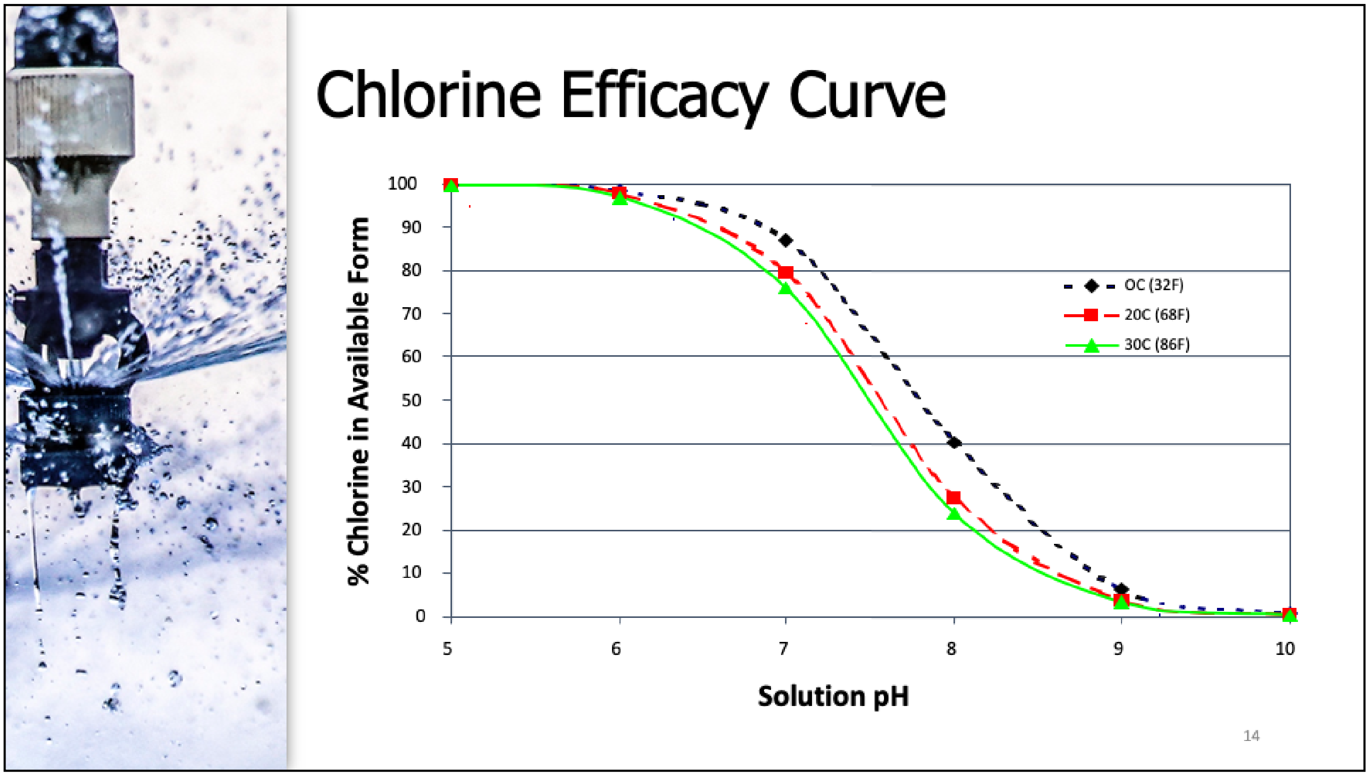
At high pH, hypochlorous acid converts to hypochlorite ion (OCl^-)

- Hypochlorite ion is relatively ineffective against pathogens

$$HOCl \longrightarrow H^+ + OCl^-$$

In high pH solutions, most of the hypochlorous acid disassociates to form hypochlorite ion (OCl-), which is not an effective sanitizer.

“Chlorine concentration, catalysts present, pH, temperature, and ultraviolet light may all affect available free chlorine during storage and use (Dychdala, 1983).”

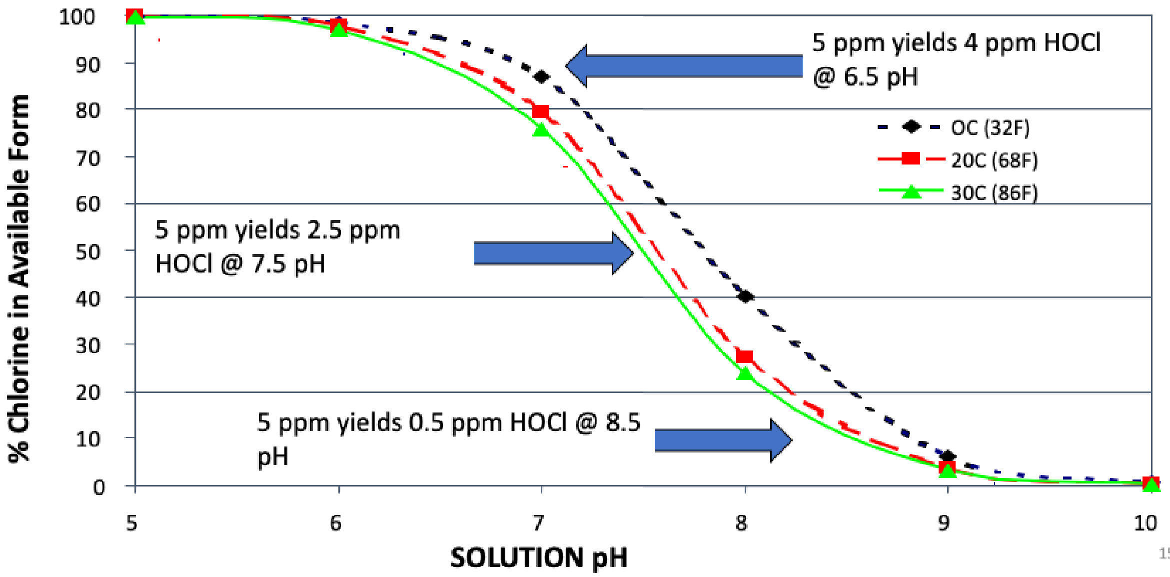


Chlorine solutions with pH above 8 are relatively ineffective against pathogens because most of the chlorine is in the ion form. As the pH rises above 7, available chlorine drops rapidly.

Additionally, chlorine gas predominates once you get to pH below 4.0, which will not readily stay in solution, which is not shown in this slide.

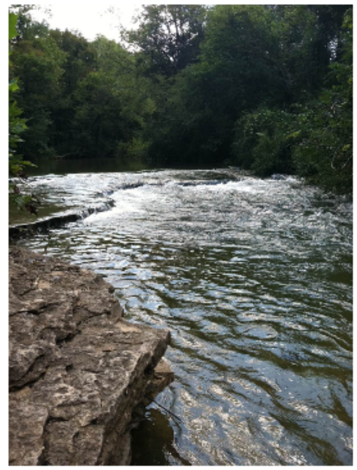
Testing kits for free chlorine measure both hypochlorous acid and hypochlorite ion and alone do not indicate the quantity of active chlorine that kills pathogens.

Free Chlorine Doesn't Always Mean Active Chlorine



What changes the pH?

- Source water
  - Geology supporting a creek or river will influence the pH
    - Geology high in carbonates tend to produce waters with higher pH
    - Geology high in iron and/or sulfur tends to produce waters with lower pH



We need to understand the pH of the source water. The geology from which the water passed through or passed over influences pH as ions from the rock and soil dissolved into the water.

What changes the pH?

- The type of chlorine used
  - Calcium hypochlorite
    $Ca(OCl)_2 + 2H_2O \rightarrow Ca^{2+} + 2HOCl + 2OH^-$
  - Sodium hypochlorite
    $NaOCl + H_2O \rightarrow Na^+ + HOCl + OH^-$

    Both add OH^-, which increases pH
- Cl_2 gas will decrease pH
  $Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$

  Releases H^+, which decreases pH

Chlorine will change the pH of water. Both types of hypochlorite release hydroxides as the chlorine compound reacts with water. The hydrogen is pulled from the water molecule to form the hypochlorous acid, leaving the hydroxide. Chlorine gas pulls the hydroxide from water molecules to form hypochlorous acid, leaving the hydrogen.

What can you do about pH?

- If you have high pH (basic), you can add some acid
  - Sodium bisulfate - $NaHSO_4$
  - Muriatic acid - HCl
  - Citric acid
- If you have low pH (acidic), you can add some base
  - Sodium carbonate (soda ash) Na_2CO_3
  - Sodium hydroxide (lye) - NaOH
- If pH control is needed, you will need to inject your acid or base separately from the chlorine
  - These are not compatible chemicals

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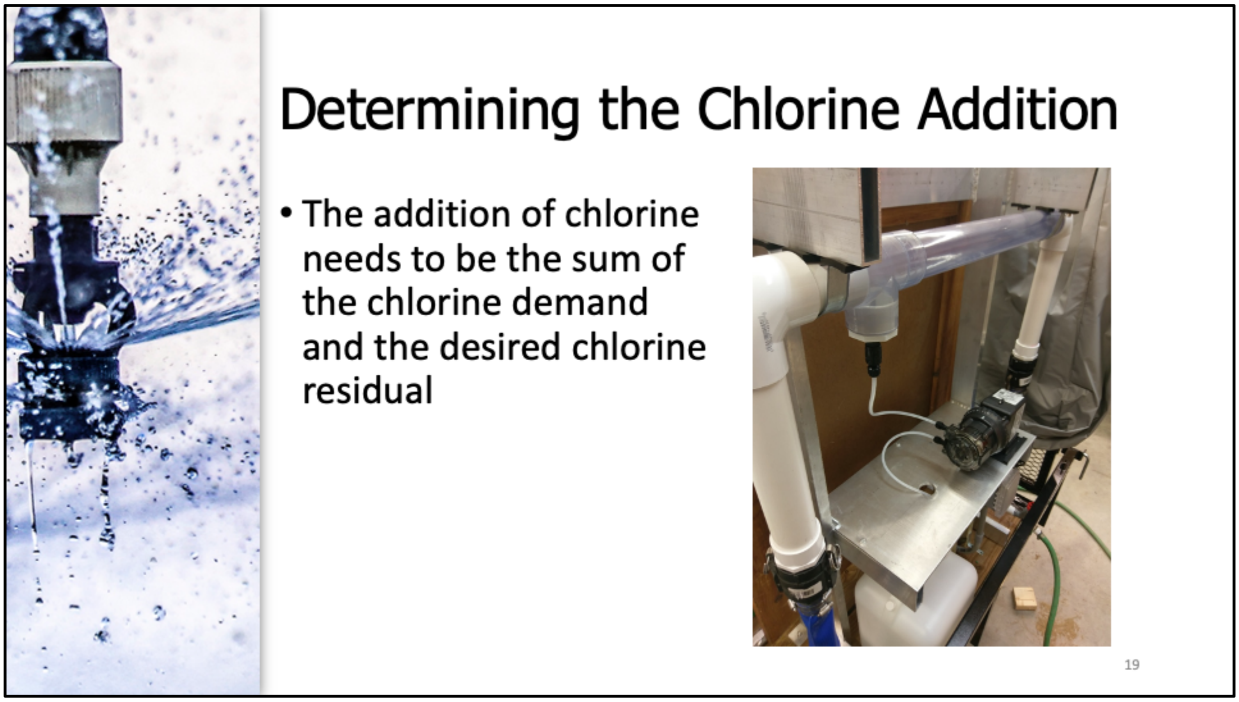
In the water treatment industry, it is very common to adjust the pH before adding chlorine. Again, it is very important to know the pH of the source water. In order to determine the amount of additives needed, it is best to take water samples (of a known volume) and add the pH adjustment in small increments. With each increment, measure (and write down) how that addition changed the pH.

A topic not covered in this presentation is alkalinity. Alkalinity is the ability to neutralize an acid – sometimes called buffering capacity. A source water that is strongly buffered will require more acid to lower the pH as compared to poorly buffered water.

Local water laboratories can be helpful in understanding the most cost effective methods to alter the pH for the best disinfection effect.



Now, we need to discuss how much chlorine to add to the water. Chlorine is a strong oxidizer and will react with other compounds in the source water, including the pathogens. The most common method is to add chlorine until there is a residual concentration of free available chlorine remaining in solution. As chlorine reacts with organic, dissolved minerals, and other compounds, the chlorine is no longer free or available.

The difference between the amount of chlorine added and the residual is the chlorine demand. An additional decision that needs to be made is the quantity of the residual. Depending on the situation, a residual of 10 ppm may be desirable. Too high of a chlorine residual may damage the soil health and the crop.

This picture show an injection system using a peristaltic pump. In order to determine the mass of chlorine being added, the user will need to know the flow rate of the irrigation system, the injection rate of the peristaltic pump, and the chlorine concentration in the concentrate tank below the pump.

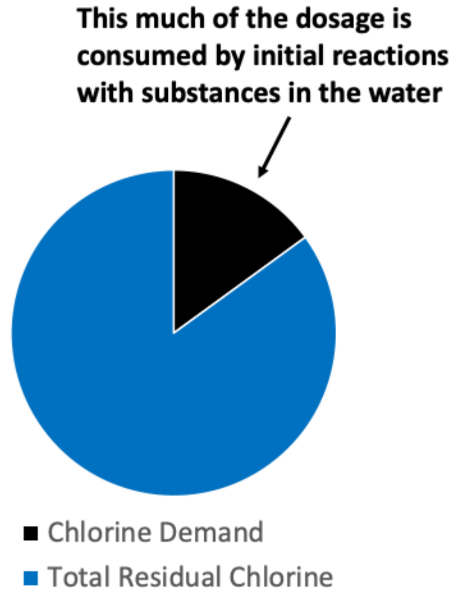
Chlorine Demand

- Chlorine reacts with other substances in water
  - "Chlorine Demand"
- This is especially significant when using surface water for irrigation where
  - There are many naturally-occurring organic compounds
  - Minerals could be dissolved in the water
- The pathogens are part of this demand

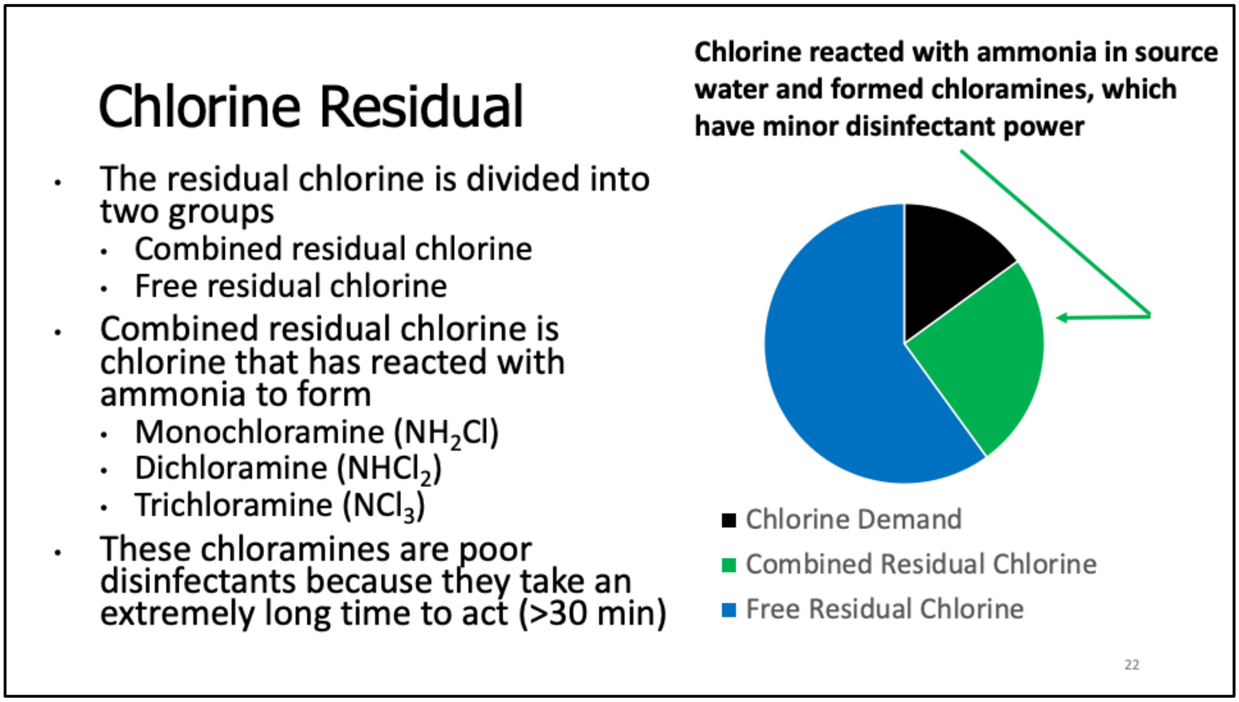
Chlorine demand: This issue is equally important as source water pH. A portion of the added chlorine is consumed as it reacts with organics and minerals. A bacterial cell is just another organic compound. It is desirable to add sufficient chlorine so that there is a residual, thus we are overloading chlorine (to a small extent). This extra chlorine provides downstream protection and can help burnout biofilms that may form in the water distribution system.

Chlorine Demand

- The chlorine demand is a fraction of the total dosage
  - It is the difference between amount of chlorine added and the residual chlorine remaining after reactions occurred
- The chlorine residual is the remaining chlorine that has disinfectant properties
  - Often this is called "total chlorine"



The chlorine demand and total residual chlorine. The residual is often called total chlorine – because this is the total that is available for disinfection.

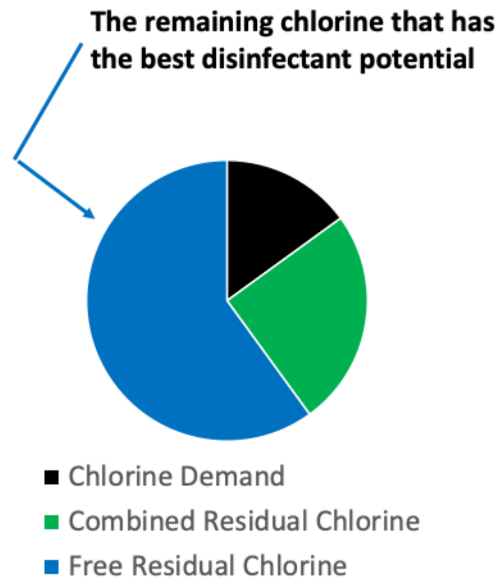


The total chlorine is comprised of combined residual chlorine and free (available) chlorine. The combined chlorine residual is chlorine that is combined with ammonia. Historically, these compounds are measured because they do have disinfectant properties and they are used by municipal water suppliers to provide disinfection out in the distribution network. Their disinfecting property is a small fraction of the free chlorine. These compounds are called chloramines.

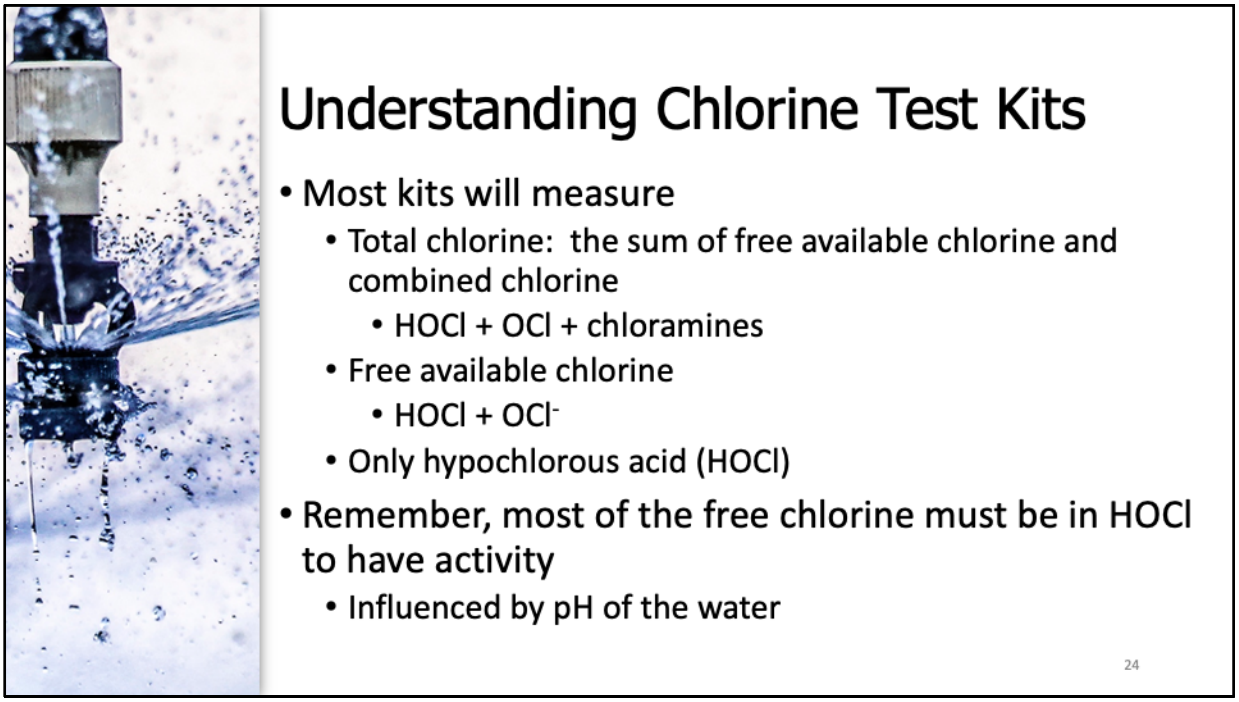
It is important to discuss the combined residual chlorine concept because some chlorine test kits measure total chlorine, and total chlorine includes the chloramines. This is a reinforcement that we need to understand exactly what the test kits measures, which will be discussed in two slides.

Chlorine Residual

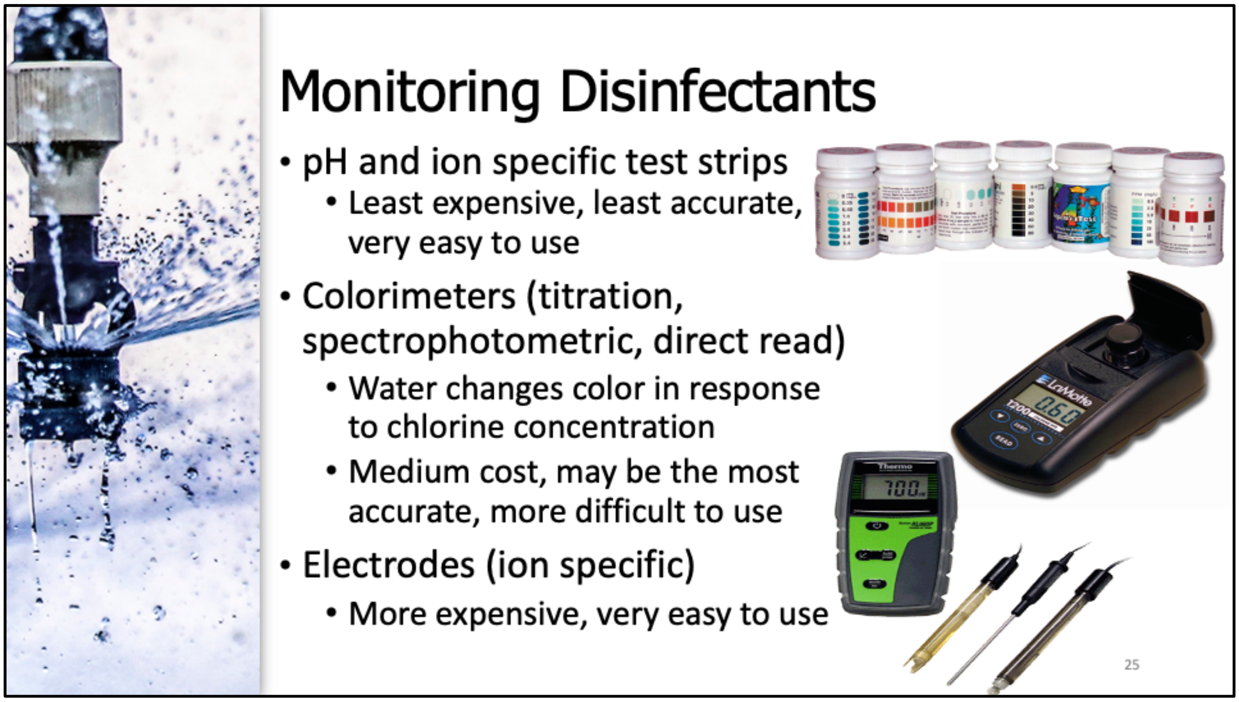
- Free residual chlorine or free available chlorine
  - The sum of HOCl and OCl^-
  - This is available downstream of the injection point



This is a reminder that free available chlorine is a fraction of total chlorine residual. And that the HOCl is the component of total chlorine that is the important one.



This next series of slides address chlorine measurement. It is important to reinforce the chlorine terminology – total residual, combined chlorine residual, free chlorine residual. Different test kits measure different aspects of chlorine chemistry.



Big picture – there are three types of chlorine measurement devices. Test strips are the least expensive and ion selective probes are the most expensive. We will discuss each of these in the following slides.

Regardless of which disinfectants are used, monitoring of their concentration is the only way to be sure that they are working in the way they are intended. Be sure to understand the monitoring system, whether it is a test strip, or an electronic monitor.

Test strips have expiration dates, be sure that you are using strips that are going to give you an accurate measurement.

Electronic meters may need calibration to give accurate results. Be sure that you read and understand the use of the device and how it is to be calibrated.

Chlorine Test Kits

- Test strips
  - Dip in the water for the prescribed length of time
  - Hold level for a few seconds
  - Compare to the attached color chart
- Need to know which chlorine compounds are measured
- Strips need to be able to measure the desired chlorine concentration

https://www.webstaurantstore.com/fmp-142-1362-sk-twc-chrome-chlorine-sanitizer-test-strips-pack/3591421362.html?utm_source=Google&utm_medium=cpc&utm_campaign=GoogleShopping&gclid=CjwKCAiAyfvhBRBsEiwAe2t_i0Bs5t0rjUuA2QA6FXXkMTCO7NxieutTIEob5CDgAWNJwv5Hx9npKhoCQRoQAvD_BwE

Least expensive and least precise. The results are given in ranges: 0 to 5, 5 to 10, 10 to 15, etc. You do not get a specific number, but you can determine if you are within a range.

These kits can be more precise and accurate. However, they are more difficult to use. A sample has to be taken and mixed with a packet to create a color change. The less expensive kits use a color chart to determine the results and the more expensive kits have a meter that provides a read out of the chlorine content.

Chlorine Test Kits

- Ion selective probe or amperometric
  - Measures movement of electrons due to oxidation and reduction of chlorine compounds
  - Requires periodic calibration
  - Can also include pH probe

https://www.astralpool.com/en/products/swimming-pool/dosing-measuring-regulation-automation-3/control-regulation-units-2/amperometric-type-2/controller-13/66168-ph-amperometric-free-chlorine-sensor/

This method can range from a handheld meter to a wall mounted unit (as shown in the slide). Ion selective probes can be very handy for a quick measurement. However, these devices require calibration using standards and they can be fouled by other compounds in the water (in other words, they need to be cleaned).

Chlorine Dosage

- The dosage required to eliminate the pathogens is a function of both chlorine concentration and the contact time
  - Disinfection is not an instantaneous process
  - The chlorine has to come into contact with the microorganisms
  - The greater the concentration, the more likely a chlorine molecule will come into contact with a microbe
  - The longer the time the water is in contact with chlorine, the more likely a chlorine molecule will come into contact with a microbe
- We assume the contact time is the duration the water is in the pipeline after the chlorine injection

Chlorine Dosage - Ct

- Dosage or Ct is concentration (C) multiplied by time (t)
  - 50 mg/L x 10 minutes = 500 mg·min/L
- This assumes that the water will be in the pipeline for 10 minutes
  - However, if the water is only in the pipeline for 3 minutes after the chlorine injection then we need 167 mg/L of chlorine to get the same dosage
  - 167 mg/L x 3 minutes = 501 mg·min/L

Dosage is NOT just the mass of disinfectant added to water, it is the combination of the disinfectant concentration and how long it is available to do it's job. If we only have a short period of time, then we need more chemical. Municipal water and wastewater disinfection allows for 20 minutes of contact time, which means lesser chlorine concentrations.

A typical irrigation system may be designed to have a water velocity between 2 and 5 feet per sec. If our irrigation mainline is 1,000 feet long, then our contact time within the mainline will be between 200 and 500 seconds (3 to 8 minutes).

Chlorine Effectiveness and Temperature

- Temperature is another important factor for water disinfection with chlorine
- Room temperature (or about 70 °F) is standard when measuring chemical activity, warmer temperatures ↑ activity and cooler temperature ↓ activity.
  - In general, every 18 °F drop in water temperature will double the required contact time
- As temperatures drop, chemical reactions take longer, thus more time is needed to ensure the disinfection process takes place

Chlorine (and all chemical disinfectants) effectiveness is influenced by temperature. Chemical activity slows as the temperature is reduced. Room temperature (or about 70 F or 21 C) is taken as a standard when measuring chemical activity, warmer temperatures create increased activity and cooler temperature create decreased activity. The molecules simply don't move as fast and there is a reduction in the collisions needed to drive the reaction.

Chlorine – Other Considerations

- Availability
  - What forms of chlorine are readily available to your operation, what does it cost?
- Worker safety
  - What are the rules associated with different forms of chlorine?
  - Chlorine gas is very dangerous, but so are other pesticides
    - May have to get operator certifications
    - May have to account for usage – recordkeeping
- Chlorine injection method
  - How do you want to transfer the chlorine from the concentrated form into the irrigation water?

Sources of Chlorine

- Chlorine gas (Cl_2)
  - Gas cylinders
- Sodium hypochlorite (NaOCl)
  - Liquid (5.25, 12.75, or 15%)
    - Residual sodium may damage crop and/or soil
- Calcium hypochlorite [$Ca(OCl)_2$]
  - Solid (65 or 68%)
    - Must work to get the powder dissolved in the irrigation water
- Chlorine dioxide (ClO_2)
  - Depending on manufacturing process, may have residual sodium
- All these form HOCl when added to water

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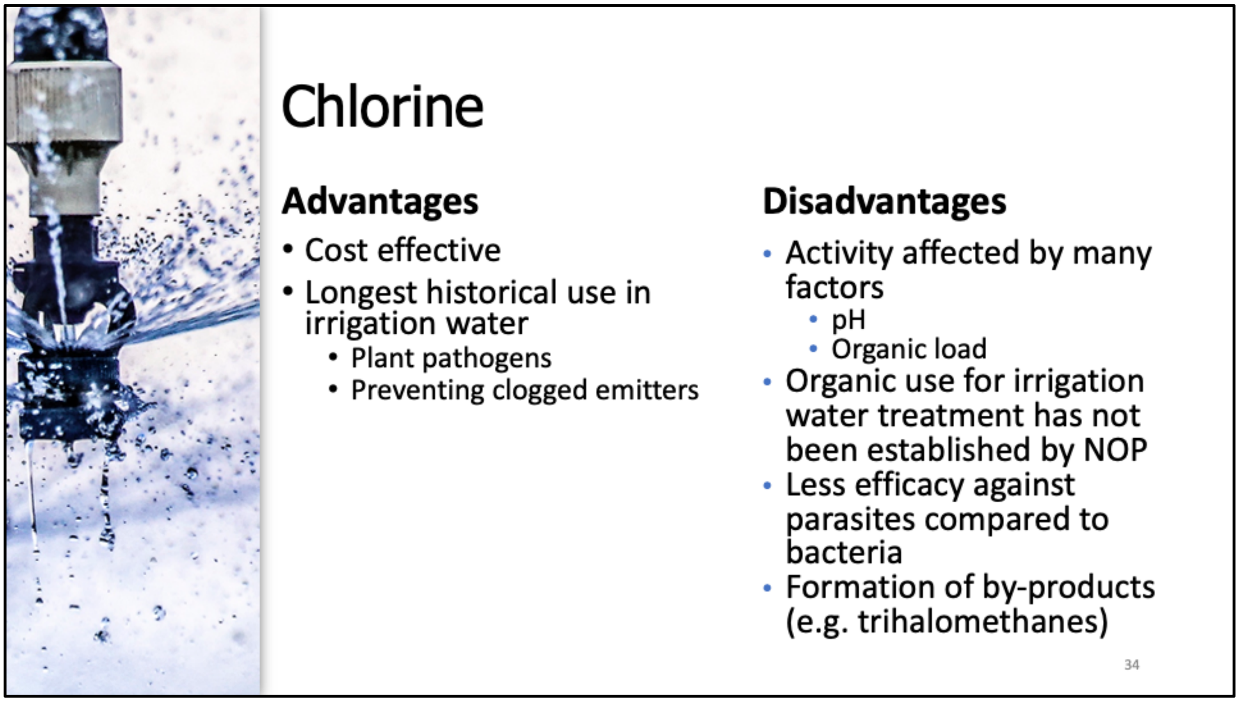
The main forms of chlorine used include sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$) and chlorine gas (Cl_2). Sodium hypochlorite is often sold as 12 to 15 % solutions. Household bleach is 5.25% sodium hypochlorite. Calcium hypochlorite usually is sold as a powder or tablets in formulations of 65%. However, it does not dissolve readily (especially in cold water) and undissolved particles can injure fruits and vegetables. To prevent this, first dissolve the powder or granules in a small amount of warm water before adding it to the tank. If using tablets for continuous, slow release of chlorine, ensure that the tablets are placed where water circulates well around them. Chlorine gas comes in pressurized gas cylinders and should be handled cautiously according to label instructions.

Chlorine dioxide has a sodium precursor. This means that a significant concentration of sodium is included with a chlorine dioxide solution –the sodium may cause plant injury.



Chlorine is relatively cheap, which is why it is so widely used. It has also been used for a relatively long time compared to other compounds for preventing clogged emitters or to prevent plant pathogens.

As we have covered, there are several factors that may influence the day-to-day effectiveness of chlorine compounds, most notably pH and organic load of the irrigation water (which can fluctuate significantly). It also isn't clear how the National Organic Program will handle application of chlorine in the field, as the use as an approved synthetic substance for organic produce is limited to postharvest washing. Lastly, chlorine has historically had less efficacy for parasites when compared to bacteria.

Chlorine Dioxide

- Gas most commonly produced by reacting sodium chlorite with an acid

Sodium chlorite	Acid		Chlorous acid		Chlorine dioxide

$$NaClO_2 + H^+ \leftrightarrow HClO_2 \leftrightarrow ClO_2$$

Chlorine Dioxide

- Currently limited to no more than 5 ppm in postharvest uses, preharvest water treatment applications will not exceed this level

Example of a product label:

1) As an antimicrobial for water systems in horticultural applications.

i) For horticulture applications, this product may be used to disinfect and control biofilm in irrigation and non-potable water at concentrations between 0.25 and 2 ppm available chlorine dioxide. Concentrations and contact times are application specific.

Chlorine Dioxide

- Chlorite and chlorate are by-products of chlorine dioxide degradation
  - Linked to decreased thyroid function and hemolytic anemia
- Upper use levels of 5 ppm chlorine dioxide have been established by the FDA to assure these by-products do not result in adverse health effects

Chlorine Dioxide

Advantages

- Not as impacted by organic matter compared to chlorine, more selective inactivation
- Does not create chlorinated by-products such as trihalomethanes
- Do not have to moderate other factors such as pH

Disadvantages

- Salinity will increase in soil as sodium will be a byproduct of chlorine dioxide generation depending on method
- Limited use levels in field, due to 5 ppm limit
- Cost
- Storage of two separate compounds that must be mixed prior to application

Peroxyacetic Acid/Peracetic Acid

$$H_2O_2 + CH_3CO_2H \leftrightarrow CH_3CO_3H + H_2O$$

Hydrogen Peroxide ✓ | Acetic Acid (Vinegar) ✓ | Peracetic Acid ✓ | Water

Peroxyacetic Acid/Peracetic Acid

- Widely used in postharvest washing
- Increasing interest in utilizing for preharvest water treatment
- Mode of action is similar to chlorine, but instead of hypochlorous acid, we are generating peracetic acid and acetic acid with the added benefit of hydrogen peroxide as an additional oxidizing compound
- pH of water will decrease as more PAA is added

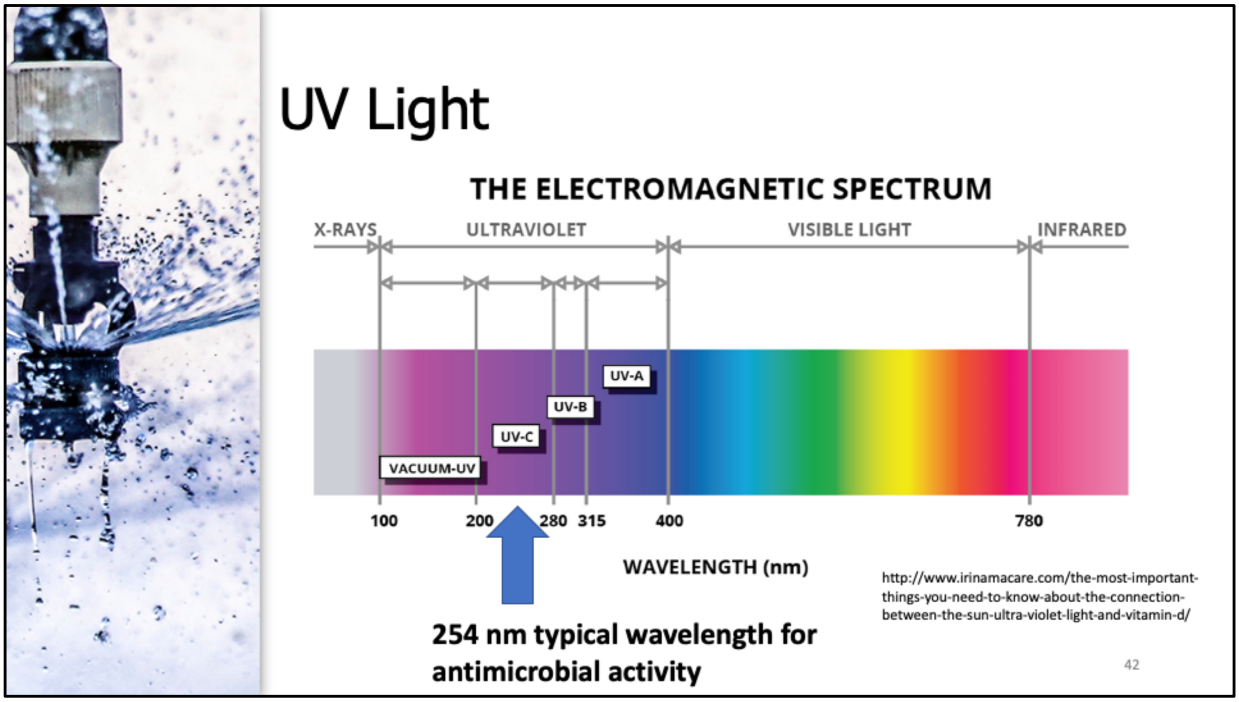
Peroxyacetic Acid

Advantages

- More resilient to organic matter compared to chlorine, but will still lose efficacy as more is added
- Not as impacted by pH of water when compared to chlorine, do not need to control for pH

Disadvantages

- Not as common for preharvest treatment for biofouling
- Cost



We have all seen the power of UV light to break down materials that are constantly exposed to sunlight. What we recognize as sunlight is composed of wavelengths from about 400 nm to 780 nm. The combination of these wavelengths produces a white color. The sun also produces wavelengths in the UV range, these are the wavelengths that are responsible for sunburns and some skin cancers.

UV-A (315 to 400 nm) accounts for 95% of UV radiation that reaches the Earth's surface. Can penetrate deeper into the skin, causes sun damage (aging) to skin.
UV-B (280 to 315 nm) affects the top layer of skin, is the cause of sunburn and strongly linked to skin cancer. Can damage the DNA in your skin. Will kill bacteria to some extent.
UV-C (100 to 280 nm) is mostly adsorbed by the Earth's atmosphere, does not reach the surface. Produced by mercury lamps, used in tanning beds, UV-C contains the germicidal range.

The peak Germicidal UV wavelength is approximately 265 nm and most low-pressure mercury lamps produce most of their radiation at 254 nm.

Mode of Action

UV light is absorbed by the DNA and RNA of microorganisms (actually, all organisms). This breaks some of the nucleotide bonds that form RNA and DNA. As a result, the next time that cell divides, it cannot do so, resulting in cell death.

Factors impacting Efficacy

Turbidity. Turbidity is a measure of light movement through water. A turbid water cannot will reflect light rather than transmit light. Turbidity is generally composed of suspended soil particles. These particles can serve as shields to prevent the UV light from reaching the microbe. UV performs best with clear water.

Hard Water. Water hardness refers to the concentration of dissolved calcium and magnesium, and other minerals that are contained in the irrigation water. These minerals can precipitate out of solution and form a scale on the quartz, thus blocking the UV light from entering the water. (The quartz is the clear protective shelve that separates the UV lamp from the water). The greater the concentration of dissolved salts, the more frequently the quartz will need to be removed and cleans.

Reactor Vessel Size. Depending on the intensity of the UV source, the water must be exposed to UV light for a fixed length of time. If the exposure time is 30 seconds and the flow rate is 500 gallons per minute, then we need a 250 gallon UV reactor vessel.

Pro's and Con's

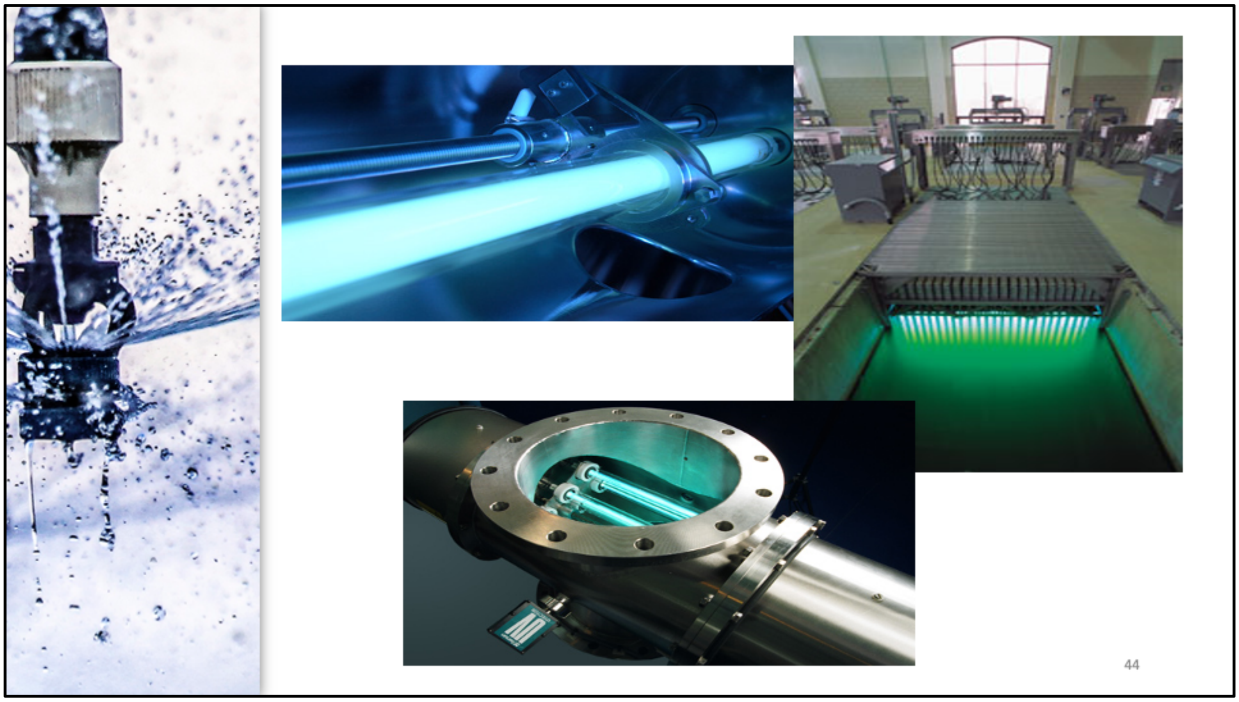
Lack of Residual: This is both a positive and a negative. As we will see with the disinfectant chemicals, the disinfection process can continue as water travels through the irrigation distribution system. Having residual disinfection activity helps to sanitize the pipes and nozzles. With UV, the disinfection process must occur while the water is in the vessel. UV cannot provide sanitation outside of the UV vessel. The positive side of no residual is the UV does not generate disinfection by-products which can detrimental to operators and to the soil health.

Economics: With UV, there is a notable up-front capital cost. UV equipment is expensive, especially as the flow rates increase. The future costs associated with UV are annual (or possibly bi-annual) lamp replacement (typically $100 per lamp) and the electric cost of operating the lamps (which is the same power demand as fluorescent lamps in your office). UV lamps fade with time and usage. The lamps may appear to be functional (NEVER DIRECTLY LOOK AT A UV SOURCE), but the actual radiation intensity may not be great enough. All UV systems used for irrigation water mitigation should include a sensor to measure the actual intensity received by the water. Chemical disinfectants have a much lower up-front cost, but require a continue supply of the chemical.

A second economic factor is UV is plug-and-play. If you have an electric source (or a generator), it is relatively easy to plumb in a UV system.

Advanced Oxidation: Advanced oxidation is the process of using UV radiation to create hydroxyl radicals (OH·) This is an advanced topic, but the short story is that UV has been used with hydrogen peroxide to create a disinfectant that is greater than the sum of UV plus hydrogen peroxide. Since PAA is partially composed of hydrogen peroxide, there is some speculation that UV could be used with PAA to create a better disinfection system that provides the benefits of both techniques. This advanced process is not ready for field use yet.

As shown, this is a UV system serving a municipal water utility. UV systems used for irrigation water mitigation should have the ability to monitor the UV intensity produced by the lamp. This monitor also provides a means to determine the effect of turbidity. If the intensity reaching the sensor, which is located on the shell of the vessel, goes below a pre-set reading – then an alarm will notify the operator that the water is not receiving an appropriate radiation dose.



Pictures of UV system that are found in municipal water and wastewater treatment systems. **Never look directly at the UV lamp**. The upper right picture shows a bank of lamps in an open channel. A similar system could be used in a irrigation canal. Most UV systems are closed vessels, in which water passes through the vessel as if it were a pipe. The UV lamps are placed in the flow of the water in order to provide the water with the most radiation exposure. The larger the diameter of the vessel, the more lamps are installed within.

UV Light

- UV-C light
- When contacts bacteria causes death by altering DNA
- Does not penetrate
  - Turbidity negatively impacts activity
- UV lamps lose activity over time
  - Most will have a 10,000 hr life
  - Changed annually
  - Cleaning of quartz glass sleeve during operation to keep growth from impacting transmission

Ultraviolet (UV) Radiation

Advantages

- Often combined with other disinfectants
- Low cost associated with system use once initial investment is paid
- No downstream activity to interact with other compounds (e.g. fertilizers or pesticides)

Disadvantages

- Water turbidity will limit effectiveness for less expensive units
- No downstream activity- will not control biofilm formation in line
- Lamp degrades, but typically will get 10,000 hrs run time

What is ozone?

Oxygen molecules

Energy can split the bound oxygen molecules into single oxygen atoms

Free oxygen will combine with oxygen molecules to form ozone

Ozone’s Activity

- Strong oxidizing capacity
- Higher electrochemical potential = greater oxidation capacity

	Electrochemical Potential (V)
Ozone	2.07
Peracetic Acid	1.81
Hydrogen Peroxide	1.77
Chlorine Dioxide	1.57
Hypochlorous Acid	0.95

Oxidation Potential in Action

- Ozone attacks cellular components
  - Lipids
  - Proteins
  - Nucleic acids

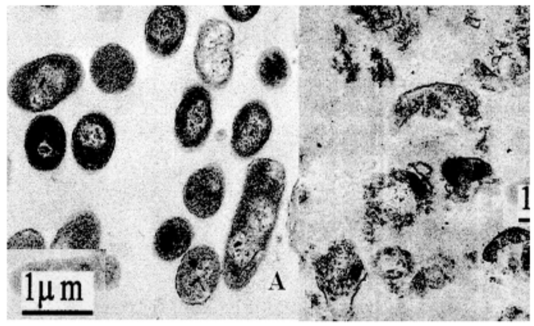


Photo courtesy of Kelly-Wintenberg (1999).

Ozone Generation

Plasma reactors provide energy needed to generate ozone

Ozone generators have been used in horticultural industries like like greenhouses for many years. The technology is used to prevent biofilm formation in irrigation system piping and tubing.

What impacts ozone concentration?

- Water temperature
  - Faster decay at higher temperatures

Temperature (°F)	Half-life (min)
59	30
68	20
77	15
86	12
95	8

Gardoni et al., 2012.

What impacts ozone concentration?

- Air temperature

Temperature (°F)	Half-life (days)
41	1.7
50	1.5
60	1.3
68	1.1
77	0.97

McClurkin, J.D. and D.E. Maier, 2010.

What impacts ozone concentration?

- Water pH
  - Higher pH (more basic) shorter ozone half-life
    - pH 8.5 or lower good target
- Organic matter
  - Increases ozone degradation
    - Shortens half-life
- Inorganic matter
  - Can serve as a scavenger
    - Decrease ozone degradation

Gardoni et al., 2012.

Other Considerations

- Employee health
  - Maximum exposure 0.1 ppm averaged over 8 hr shift (OSHA)
  - Short-term exposure 0.3 ppm for 15 min ≤ 2 times a day
  - Irritating to the upper and lower respiratory tract
  - Monitor air to demonstrate compliance

Ozone

Advantages

- Highest oxidation capacity
- Treats biofilms
- No residues

Disadvantages

- Rapid degradation at higher temperatures
- Cost
- Professional design/install
- On-site generation
- Worker safety

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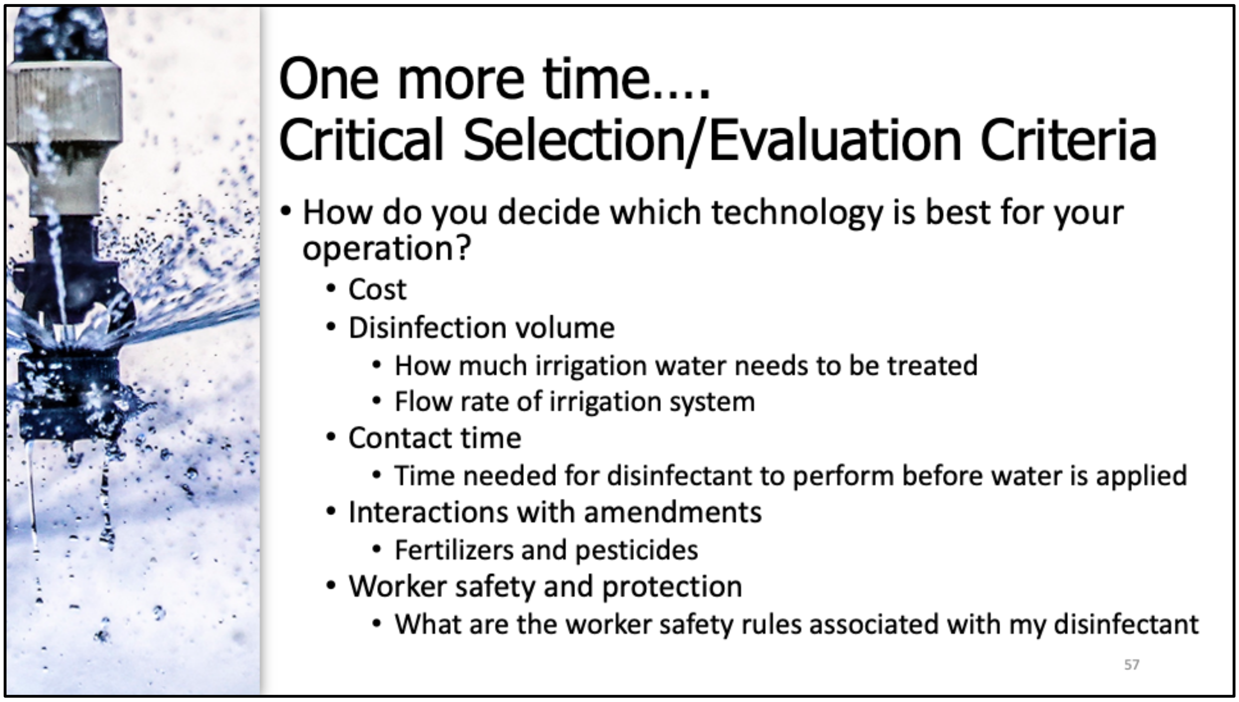
Ozone is a gas and has several advantages over other sanitizers. The first is that it can be effective against biofilms. Helping to break down those biofilms in irrigation systems. As ozone breaks down, many of the breakdown products that form during those chemical reactions also have the ability to breakdown microbes. Finally, there is no residue left after ozone has been used.

The disadvantages of using ozone are its rapid degradation. It has to be continuously generated to be present. If the system turns off, or stops working, the sanitizer production immediately stops. It can not be stored, it must be generated as it is used.

Systems using ozone are not do-it-yourself, they must be professionally installed and require electricity to be generated. There are worker safety considerations with the use of ozone, due to its toxicity, which must be managed when using ozone.



Critical Selection/Evaluation Criteria
Use this slide as a review to how we might evaluate which disinfection technology is best for the operation. Discuss issues such as how big is the production operation, how many water sources are used, who will be operating the disinfection system

Disinfection Volume:
Irrigation volume: Does the irrigation system apply acre-inches or acre-feet of water? Two inches per week over 10 acres is 543,000 gallons per week (one acre-inch is 27,156 gallons). If you are going to apply 20 ppm of Active Ingredient chlorine, you have to add 133 pounds of Ca(ClO)2 per week.

Irrigation Flow Rate: What is the flow rate of the irrigation system? If it applies water at 200 gallons per minute, your injection system needs to add Ca(ClO)2 at approximately 23 grams per minute.

Contact time: the amount of time the disinfectant needs to perform. Contact time can be the time the water is exposed to UV, of how long water and chlorine are in the irrigation distribution pipe before the water contacts the crop.

Interaction with Amendments: If using fertigation or chemigation, will the disinfectant react with the fertilizer or pesticide?

Worker Safety and Protection: Disinfecting the human being can result in painful disfigurement and/or death. What degree of worker competence is available to operate the equipment? What type of worker safety training is required?

Summary

- No approach is perfect, analyze cost based upon your irrigation use
- EPA registered pesticide products must have a label that MUST allow for their use in irrigation water
  - This will provide limits for use
  - Produce Safety Alliance - http://bit.ly/PSA_sanitizer
    - Scroll to ”Sanitation”- Searchable Excel spreadsheet with links to labels
- Any investment should help achieve goal of inactivating foodborne pathogens

Questions?

Washington State University Extension

NC State Extension

UT Extension Institute of Agriculture, The University of Tennessee

SC Southern Center for Training, Education, Extension, Outreach, and Technical Assistance to Enhance Produce Safety

Virginia Cooperative Extension, Virginia Tech • Virginia State University

UF IFAS Extension, University of Florida

USDA NIFA

United States Department of Agriculture National Institute of Food and Agriculture

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