Principles of Chlorine Dioxide Gas as a Decontamination Method
Principles of Decontamination

In order for any decontamination method to be effective, the following points must be satisfied:

The decontamination method must:

- Be able to kill the organism in question
- Achieve good and complete distribution
- Achieve thorough and total penetration
- Achieve sufficient contact time at the correct concentration
Traditional sanitation methods can have difficulty guaranteeing that all organisms have been contacted / contacted with the proper dosage.

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History of Chlorine Dioxide

A Brief Summary:

1811
First Preparation of Chlorine Dioxide

1912
Aqueous Germicide (Drinking Water Treatment Longest User)

1940
Bleaching Agent (Pulp & Paper Industry Largest User)

1984
Chlorine Dioxide Recognized as a Gaseous Chemosterilizing Agent

2001
First Registered with the US-EPA for use as a sterilant
Chlorine Dioxide Gas Process

- **Pre-Conditioning**
  Raise relative humidity to 65-75%

- **Conditioning**
  Hold that humidity level for a short period of time

- **Charge**
  Inject CD Gas to a concentration of 1 - 5 mg/L

- **Exposure**
  Hold time at that CD Gas concentration

- **Aeration**
  Remove CD Gas
ClorDiSys’ Chlorine dioxide gas is registered as a sterilant with the US EPA, which means it is capable of eliminating all viruses, bacteria, fungi and spores.
Spores are considered the hardest organism to eliminate, compared to live viruses and bacteria which are considerably easier.

<table>
<thead>
<tr>
<th>Target Organism</th>
<th>Dosage Required using CD Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonella</td>
<td>~100 ppm-hrs for 6-log kill</td>
</tr>
<tr>
<td>Listeria</td>
<td>~300 ppm-hrs for a 5-log kill</td>
</tr>
<tr>
<td>Spores</td>
<td>~600 ppm-hrs for 6-log kill</td>
</tr>
<tr>
<td>ClorDiSys Decon Cycle</td>
<td>720 ppm-hrs</td>
</tr>
</tbody>
</table>
Humidity’s Role Towards Efficacy

Chlorine dioxide has been validated to be effective at lower relative humidity, but requires a higher dosage

<table>
<thead>
<tr>
<th>RH</th>
<th>Dosage Required for 6-log Spore Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>65%</td>
<td>~600 ppm-hrs</td>
</tr>
<tr>
<td>55%</td>
<td>~1000 ppm-hrs</td>
</tr>
<tr>
<td>45%</td>
<td>~1550 ppm-hrs</td>
</tr>
</tbody>
</table>
As Chlorine Dioxide Gas is water soluble, it is able to maintain its efficacy within water, so areas do not have to be completely dry for the process to work.

As wash downs and manual cleaning traditionally occur prior to decontamination, using chlorine dioxide gas means that surfaces do not need to be completely dry prior to decontaminating.
A chemical can’t kill what it can’t reach.

**Distribution**

<table>
<thead>
<tr>
<th></th>
<th>Chlorine Dioxide Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point</td>
<td>51°F</td>
</tr>
<tr>
<td>Natural State at Room Temperature</td>
<td><strong>Gas</strong></td>
</tr>
</tbody>
</table>

Gasses fill the space they are contained within evenly and completely.

Chlorine Dioxide Gas is able to evenly fill the area it is decontaminating, no matter how large, tall or filled with equipment.
Distribution
Distribution

86'
Penetration into Crevices
Organisms sizes vs ClO₂ molecule

Magnified scratch in stainless steel harboring bacteria
Equal concentrations of CD Gas and Liquid used

All the treatments were for 10 min at 20°C

(Han, Y. et al, Reduction of Listeria monocytogenes on Green Peppers (Capsicum annuum L.) by Gaseous and Aqueous Chlorine Dioxide and Water Washing and Its Growth at 7°C, Journal of Food Protection, Vol 64, No 11, 2001 pages 1730-1738)
## Efficacy & Validation

<table>
<thead>
<tr>
<th>QA Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration Monitor</td>
<td>Verifies the concentration of CD gas during a decontamination and overall cycle dosage</td>
</tr>
<tr>
<td>Biological Indicators</td>
<td>Verifies that the decontamination cycle achieved 6-log sporicidal reduction</td>
</tr>
<tr>
<td>Swab Testing</td>
<td>... you know this one.</td>
</tr>
</tbody>
</table>
Chlorine Dioxide Gas

<table>
<thead>
<tr>
<th>Color</th>
<th>Yellow-Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>uv-vis</td>
</tr>
<tr>
<td>Monitoring</td>
<td>spectrophotometer</td>
</tr>
</tbody>
</table>

Thanks to its yellow-green color, chlorine dioxide is able to be accurately monitored using a photometer.

The higher the concentration of gas, the deeper (darker) the color gets. The photometer measures the depth of color of the gas and converts it to a highly-accurate concentration reading.
Contact Time and Dosage

You can hold the true concentration for the contact time necessary to achieve the dosage required for a complete decontamination.

Area under the curve is a highly accurate dosage measurement.
The decontamination is not considered to be complete until all concentration monitoring locations exceed the proper dosage.
Biological indicators consist of a semi-permeable outer packaging and an interior carrier impregnated with bacterial spores. For sterilization, BI’s contain over 1 million bacterial spores, providing the ability to prove a 6-log (99.9999%) sporicidal reduction.
After the decontamination process is complete, BI’s are collected and aseptically dropped into growth media tubes and incubated. If any spores were not killed in the BI, they will grow and the bacteria will multiply causing turbidity (cloudiness) or a color change within the media tube. Each BI/media combination has a validated incubation time which is how long you must wait before taking a final reading on the BI for growth. CD gas has a 36-48 hr incubation time depending on BI manufacturer.

**Positive for growth**
(Decon unsuccessful)

**Negative for growth**
(Decon successful)
Penetration into Open and Closed Cabinets

BI Placed in OPEN Cabinet

BI Placed in CLOSED Cabinet

BOTH BIs Killed
Penetration Inside Jars

- **Bls Killed**
  - Open jar
  - Lid placed on top of jar

- **Bls Killed**
  - Open jar
  - Lid sealed on jar

- **Bls NOT Killed**
Penetration into Grain, Powdered Milk, Protein Powder, Sugar, Flour, Baby Formula

ALL BIs Killed
## Cycle Flexibility

<table>
<thead>
<tr>
<th></th>
<th>Chlorine Dioxide Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>Not a factor above 52 F</td>
</tr>
<tr>
<td><strong>Starting Relative Humidity</strong></td>
<td>Not a factor</td>
</tr>
<tr>
<td><strong>Equipment Within Space</strong></td>
<td>Not a factor, gas gets everywhere</td>
</tr>
<tr>
<td><strong>Room Shape / Size</strong></td>
<td>Not a factor, gas gets everywhere</td>
</tr>
<tr>
<td><strong>Injection Point Location</strong></td>
<td>Not a factor, gas gets everywhere</td>
</tr>
</tbody>
</table>
Chlorine Dioxide Gas is able to achieve the requirements for a successful decontamination naturally due to its chemical properties.

The decontamination method must:

- Be able to kill the organism in question
- Achieve good and complete distribution
- Achieve thorough and total penetration
- Achieve sufficient contact time
- at the correct concentration
Material Compatibility
# Oxidation Potential

<table>
<thead>
<tr>
<th>Biocidal Agent</th>
<th>Oxidation Potential (volts)</th>
<th>Oxidation Capacity (electrons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>2.07</td>
<td>2e-</td>
</tr>
<tr>
<td>Peracetic acid</td>
<td>1.81</td>
<td>2e-</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
<td>1.78</td>
<td>2e-</td>
</tr>
<tr>
<td>Bleach</td>
<td>1.49</td>
<td>2e-</td>
</tr>
<tr>
<td>Chlorine Dioxide</td>
<td>0.95</td>
<td>5e-</td>
</tr>
</tbody>
</table>

Chlorine Dioxide is scientifically gentler on materials than these other sterilant methods.
Chlorine dioxide does not last long enough to be bottled and shipped, so it must be generated on demand. Depending on the method in which chlorine dioxide is generated, the end product can vary greatly.

**ClorDiSys** generates pure chlorine dioxide for decontamination

(4% Chlorine Dioxide – 96% Nitrogen)

Other methods of generating chlorine dioxide (liquid or gas) generate acidic byproducts along with the chlorine dioxide

Base + Water + Activator → **Acidified Sodium Chlorite** + **Chlorous Acid** + **Chlorine Dioxide**
No Residue

ClorDiSys CD Gas has no residues

One of the first commercial uses for ClorDiSys’ (Then J&J’s) chlorine dioxide gas was to sterilize implantable contact lenses. It was proven to the FDA that this sterilization method left no measurable residuals.

We are starting to receive FDA approvals for treating food products with our chlorine dioxide gas as well. Each approval requires residual testing to prove that the food is safe to eat.
Material Compatibility

**CD gas is safe on:**
- Stainless steel
- Galvanized metals
- Anodized aluminum
- Painted / coated metals
- Plastics
- Epoxy Paints / Coatings
- Electronics

**CD can affect:**
- Unpainted ferrous metals
- Urethane Foam
- Some Natural Rubbers
Safety
How to Decontaminate Safely

The key component to decontaminating a space safely is to contain it within the area you are treating. This can be done through the following steps:

- Sealing all penetrations leading in / out of the space (such as pipes)
- Sealing off the HVAC system handling the space (where applicable)
- Sealing off the doors and entry points to the space
Current Uses:

- Over 700 municipalities use chlorine dioxide to disinfect their public drinking water.
- Used in poultry processing rinse water
- Used in fruit and vegetable rinse water
- Listed as an allowed substance on its National Organic Program’s National List of Allowed and Prohibited Substances

Chlorine Dioxide is not classified as a carcinogen by any health agency
## Odor Threshold

<table>
<thead>
<tr>
<th></th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSHA 8 hr TWA</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Typical Concentrations</td>
<td>360 ppm</td>
</tr>
<tr>
<td>Odor Detection</td>
<td>YES At 8 hour safety level</td>
</tr>
</tbody>
</table>

The smell of CD is distinguishable from, but similar to the smell of chlorine. This is beneficial as chlorine’s odor is widely known and recognized, so there is no learning curve for personnel in recognizing when there is CD present. While one’s nose is not meant to be used as a primary means of odor detection due to the variance in sensitivity to smell that personnel have, it provides an extra layer of personal protection.
The chemical properties of chlorine dioxide make it well suited for space decontamination.

Chlorine dioxide gas is able to achieve a complete 6-log sporicidal decontamination of all surfaces within a space, including hard-to-reach areas such as crevices.

This allows it to successfully treat large areas all at once without missing any organisms.
Untreated and stored for 6 weeks at 4°C

Treated with 10 mg/l Chlorine dioxide gas for 10 min and stored for 6 weeks at 4°C

Han Y., Linton, R.H., and Nelson, P.E., Inactivation of *Escherichia coli* O157: H7 and *Listeria monocytogenes* on strawberry by chlorine dioxide gas, annual meeting of Institute of Food Technologists, Anaheim, CA, 2002.