Understanding the Chemistry of Healthcare Approved Cleaner Disinfectants

CAEM (Canadian Association of Environmental Management)
Sea What’s on the Horizon Conference and Trade Show

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Understanding the Chemistry of Healthcare Approved Cleaner Disinfectants

OUTLINE

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II. Requirements for an Ideal Disinfectant
III. Factors that Impact Disinfectant Activity
IV. Quat Based Disinfectants
V. Alcohol Based Disinfectants
VI. Hypochlorite Based Disinfectants
VII. Peroxide Based Disinfectants
VIII. Technology Comparison
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XI. Q&A
I. Why worry about Surface Disinfection?

- **Common Microorganisms cause HAIs**

Top 10 Health Care Associated Pathogens

- *Staphylococcus aureus*
- *Escherichia coli*
- Coagulase Negative *Staphylococcus*
- Candida and other yeasts
- *Enterococcus* spp
- *Pseudomonas aeruginosa*
- Klebsiella spp
- *Enterobacter* spp
- Other *Streptococci*
- *Clostridium difficile* and other anaerobes

I. Why worry about Surface Disinfection?

Microorganisms can Persist on Surfaces

G⁻ bacteria:
- *Acinetobacter* spp. – up to 5 months
- *Escherichia coli* & *Pseudomonas aeruginosa* – up to 16 months
- *Klebsiella* spp. – up to 30 months

G⁺ bacteria:
- *Enterococcus* spp. including VRE – up to 4 months
- *Clostridium difficile* spores – up to 5 months
- *Staphylococcus aureus*, including MRSA–up to 7 months

Viruses:
- Respiratory and bloodborne viruses – up to several days
- Norovirus – up to 7 days
- Rotavirus & Poliovirus -- up to 2 months

Yeast:
- Candida – up to 4 months

I. Why worry about Surface Disinfection?

Microorganisms can be Transmitted from Surfaces

“There is now compelling evidence that contaminated surfaces make an important contribution to the epidemic and endemic transmission of *C. difficile*, *VRE*, *MRSA*, *A. baumannii*, and *P. aeruginosa* and to the epidemic transmission of *norovirus*.”

I. Why worry about Surface Disinfection?

Take Home Message:

The risk of spreading HAIs may be increased due to Healthcare surfaces contaminated with persistent pathogens that serve as sources for transmission.

Intervention is Required

Routine Surface Disinfection is vital as part of a multi-pronged approach to reduce the occurrence of healthcare-associated infections.
II. Requirements for an Ideal Disinfectant

An ideal disinfectant would be …

- Fast, broad spectrum antimicrobial activity against the major classes of microorganisms, including *C. difficile* spores
- Fully active in the presence of organic matter.
- One step product (cleaner/disinfectant)
- RTU (Ready to Use) with 12-24 month shelf life
- Safe for humans (non-toxic, non-allergenic, non-irritating)
- Safe for the environment during use and disposal
- Odorless, non-staining
- No residue
- General material compatibility (metals, rubbers, plastics, other)

In reality, however, there are always tradeoffs!
No one disinfectant meets all needs!
III. Factors that Impact Disinfectant Activity

Microorganism Type

• Bacteria, Virus, Fungus
• Age of Microorganism
• Stress Response – Spore Forming?

Environment

• Temperature, Humidity, Nutrient Source
• Macro community (Biofilms, Other Microorganisms)
• Presence of foreign matter

Product Type → Today’s Discussion

• Active Ingredient
• Product Formulation
III. Factors that Impact Disinfectant Activity

Which Active Ingredient is “Best”? 

Quat. Based Disinfectants?

Alcohol Based Disinfectants?

Hypochlorite Based Disinfectants?

Peroxide Based Disinfectants?

Let’s look at the different chemistries!
IV. Quat Based Disinfectants: What are Quats?

A Quat, “QAC”, or quaternary ammonium compound, is an organic compound that contains at least one cationic (positively charged) nitrogen atom, which is referred to as the “quaternary nitrogen atom”.

\[
\begin{array}{c}
\text{R}^1 \\
\text{R}^2 \\
\text{R}^3 \\
\text{R}^4 \\
\end{array}
\]

Quats also are: Surface-active agents that break down the cell walls of microbes causing leakage of the internal contents.

• There are many quaternary ammonium products.
• Their properties depend on type of R groups, the counter anion, and the number of quaternary nitrogen atoms (monomeric, bis, polymeric).
IV. Quat Based Disinfectants: What are Quats?

Examples of Quat Species

Monomeric Quats
(Benzalkonium Chloride)

Bis Quats
(Biguanides, CHG, Barquat)

Polymeric Quats
(Polyhexamethylene Biguanide, PHMB)
IV. Quat Based Disinfectants: Microbicidal Activity

Quat Hospital Disinfectants are typically

- Bactericidal
- Fungicidal
- Virucidal against lipophilic (enveloped) viruses

They are generally NOT

- Tuberculocidal
- Virucidal against hydrophilic (nonenveloped) viruses

They are NOT

- Sporicidal
## IV. Quat Based Disinfectants: Examples

<table>
<thead>
<tr>
<th>Generation</th>
<th>Quat/Quat Mixture</th>
<th>Example</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 1st        | Benzalkonium Chloride with specific alkyl distributions | ![Chemical Structure](image)
|            |                   | $n = 8, 10, 12, 14, 16, 18$ | Biocidal efficacy impacted by hydrophilic-lipohphlic balance
|            |                   |         | n=14 provides peak biocidal activity
|            |                   |         | Issue $\rightarrow$ toxicity |
| 2nd        | Substituted Benzalkonium Chlorides | BTC 471 -- alkyl(dimethylethyl)benzyl ammonium chloride | Modifications of 1st generation quats by substitution of chlorine, methyl, or ethyl groups on the aromatic ring |
| 3rd        | Dual Quats | BTC 2125M, a synergistic mixture of alkyl(dimethyl)benzyl ammonium and alkyl(dimethylethyl)benzyl ammonium chlorides. Very common, for example, EPA Reg. 1839-83, RTU, >1000 prods | Greatest Commercial Significance $\rightarrow$ Improved performance $\rightarrow$ increased biocidal activity, stronger detergency, and reduced toxicity |
| 4th-7th    | Twin Chains, Synergistic Combinations, Polymers | Varies | Some in use, Issues $\rightarrow$ Cost, lack of commercial availability, sacrifice efficacy for reduced toxicity, most not registered for use as actives |
IV. Quat Based Disinfectants: How Quats Work

Quats are:

- Surface-active agents
- Attracted to negatively charged cell surfaces

Key Effects:

- Break down the cell walls of microbes
- Disruption of the cell membrane
- Inactivate energy-producing enzymes
- Denature essential cell proteins
- Cause leakage of the internal contents.
- CELL DEATH!
## IV. Quat Based Disinfectants: Properties

<table>
<thead>
<tr>
<th>Typical Quat Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Stable Products</td>
<td>Long (unrealistic) contact times can be up to 10 minutes</td>
</tr>
<tr>
<td>Non-irritating to skin</td>
<td>Efficacy is reduced in the presence of organic matter.</td>
</tr>
<tr>
<td>Non- corrosive to metals and other surfaces</td>
<td>May leave residue on surfaces</td>
</tr>
<tr>
<td>Low toxicity/Mild odor</td>
<td>Not effective against non-enveloped viruses, TB, spores, bio-films unless mixed with other additives</td>
</tr>
<tr>
<td>Don’t damage clothing/carpets</td>
<td>Toxicity for some concentrates</td>
</tr>
<tr>
<td>Usually formulated with cleaning agents</td>
<td></td>
</tr>
</tbody>
</table>
V. Alcohol Based Disinfectants: What are Alcohols?

Alcohols are volatile organic chemical compounds that contain at least one hydroxyl (-OH) group.

Alcohol based disinfectants typically use Ethanol (EtOH) or Isopropyl Alcohol (IPA).

Alcohol solutions are most effective when diluted with water in order to improve diffusion through cell membranes.

- 70% EtOH or IPA has broad spectrum bacterial efficacy.

EtOH and IPA are commonly used for hand sanitizers and patient skin prep (i.e. Antiseptics) due to rapid efficacy.
V. Alcohol Based Disinfectants: Microbicidal Activity

Alcohol Hospital Disinfectants are typically

- **Bactericidal**

Higher concentrations or mixtures are typically required before alcohols are

- **Virucidal against lipophilic (enveloped) viruses**;

They are generally only partially

- **Virucidal against hydrophilic (nonenveloped) viruses**

They are NOT

- **Fungicidal or Sporicidal**  (Note: Alcohol hand sanitizers are NOT effective against *C. difficile*)

The efficacy of alcohol can be improved by including quats or wetting agents in the formulation.
V. Alcohol Based Disinfectants:
How Alcohol/Quats Work

Quats + Alcohol Synergy

• 1st the Quat breaks down the microorganism lipoprotein complexes in the cell membrane

• Once the membrane is open, the alcohol is then able to penetrate the cell membrane and cause irreversible structural damage to the cell.
## V. Alcohol Based Disinfectants: Alcohol Properties

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad spectrum efficacy -- bactericidal (including TB), virucidal, fungicidal</td>
<td>Not effective against <em>C. difficile</em> spores</td>
</tr>
<tr>
<td>Rapid Contact Times</td>
<td>Exposure may cause skin drying and irritation</td>
</tr>
<tr>
<td>No residual chemistry left on surfaces</td>
<td>Not compatible with some plastics</td>
</tr>
<tr>
<td>Doesn’t stain</td>
<td>Source of VOCs (volatile organic compounds)</td>
</tr>
<tr>
<td>Often added to Quat products to improve efficacy and contact time of product</td>
<td>Rapid evaporation, multiple wipes may be required to achieve contact times</td>
</tr>
<tr>
<td>Non corrosive,</td>
<td>Pre-cleaning required</td>
</tr>
<tr>
<td></td>
<td>Flammable</td>
</tr>
<tr>
<td></td>
<td>Limited efficacy in the presence of organic material.</td>
</tr>
</tbody>
</table>
VI. Hypochlorite Based Disinfectants: What is Hypochlorite Bleach?

Sodium Hypochlorite – NaOCl

Aqueous solutions of NaOCl are commonly called “Bleach”

\[ \text{NaOCl} + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{NaOH} \]

• Since 1913, hypochlorite bleach has been one of the most widely used disinfectant products due to its proven efficacy against hospital microorganisms.

• Strong oxidizing agent – reacts with enzymes, amino acids, proteins.

• Causes rapid, non-specific destruction of proteins.

• Hypochlorite bleach is manufactured from sodium chloride (common table salt) and water to produce sodium hypochlorite.

• NaOCl breaks down mainly into salt and water during or quickly after use.

• Hypochlorite based disinfectants are water solutions of NaOCl that may or may not contain additives for enhanced cleaning and stability.
VI. Hypochlorite Based Disinfectants: What is Hypochlorite Bleach?

- Jug Bleach
  - ~5-6% NaOCl
- Self diluted bleach
  - ??
- Ready-to-Use
  - ~ 0.5% NaOCl
VI. Hypochlorite Based Disinfectants: Microbicidal Activity

Hypochlorite Based Hospital Disinfectants are typically:

- Bactericidal
- Fungicidal
- Virucidal against lipophilic (enveloped) viruses;
- Virucidal against hydrophilic (nonenveloped) viruses
- Tuberculocidal – depending on concentration and formulation

They may be:

- Sporicidal – depending on concentration and formulation
VI. Hypochlorite Based Disinfectants: How Hypochlorite Bleach Works

• Activity based on Hypochlorous Acid, HOCl → Strong Oxidizer.
  \[ \text{NaOCl + H}_2\text{O} \rightarrow \text{HOCl} + \text{NaOH} \]

• Tears apart the microbe’s cell walls and deactivates proteins required for bacterial growth by destroying the molecular structure.

• Sporicidal depending on pH and concentration. During treatment, the spores lose the ability to germinate, the spore coat separates, and cell death occurs.

• Generally → broader range of microorganisms, lower contact times than Quats
## VI. Hypochlorite Based Disinfectants: Properties

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid &amp; broad spectrum efficacy -- bactericidal (including TB, and <em>C. difficile</em> spores), virucidal, fungicidal</td>
<td>Unstable unless stabilizing agents are added to the formulation</td>
</tr>
<tr>
<td>NaOCl Bleach formulas ≥ 1:10 concentration meet CDC Guidelines for Surface Disinfection and OSHA Bloodborne Pathogen Standards</td>
<td>Caustic, tends to corrode metals unless an anticorrosive agent is included in the formulation.</td>
</tr>
<tr>
<td>Destroys Allergens, Removes Mold and stains, controls odors</td>
<td>Deactivated in presence of organic matter.</td>
</tr>
<tr>
<td>Removes dried organisms &amp; biofilms</td>
<td>Salt Residue can be left on surface</td>
</tr>
<tr>
<td>Low toxicity, No toxic residues</td>
<td>Discolors or “bleaches” fabrics</td>
</tr>
<tr>
<td>Can be formulated with cleaning agents. Unaffected by water hardness</td>
<td>Incompatible with ammonia, acids, formaldehyde</td>
</tr>
<tr>
<td>Inexpensive and Fast Acting</td>
<td></td>
</tr>
</tbody>
</table>
## VI. Hypochlorite Based Disinfectants: Comparison

<table>
<thead>
<tr>
<th>Liquid “Jug” Bleach (~5-6% NaOCl)</th>
<th>Formulated 1:10 Ready-to-Use Products (~0.55% NaOCl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At high concentrations skin, eye, or respiratory irritations possible</td>
<td>Low, but effective, concentrations used.</td>
</tr>
<tr>
<td>Deactivated in presence of significant amounts of organic matter, degrades with time</td>
<td>Stabilizing agents may be added to improve stability and to insure effective concentration</td>
</tr>
<tr>
<td>Caustic, tends to corrode metals</td>
<td>Anticorrosive agents may be added.</td>
</tr>
<tr>
<td>2 Step – Must first clean the surface and then disinfect it.</td>
<td>Maybe 1 Step – Cleaning agents may be added – check label instructions!</td>
</tr>
<tr>
<td>Dilutions must be made up daily, increased splash/spill risk</td>
<td>Product is ready to use until the expiration date</td>
</tr>
</tbody>
</table>
VII. Peroxide Based Disinfectants: What is Peroxide?

Hydrogen Peroxide ...

- **Powerful Oxidizer** that is often used as a bleaching or cleaning agent.
- **Natural metabolite** of many organisms. The organisms then typically decompose the $\text{H}_2\text{O}_2$ they produce into oxygen and water.
- **Natural environmental purifier** that can be formed by the action of sunlight on water.
- **Does not release troublesome gas or leave chemical residues** that are associated with other chemical oxidants.
- **Safety depends on concentration.** Industrial strength $\text{H}_2\text{O}_2$ is a strong oxidizer and as such requires special handling precautions.
VII. Peroxide Based Disinfectants: What is Peroxide?

- 3% Solution Antiseptic
- Pulp and Paper Whitening
- Rocket Fuel
- Bombardier Beetle
- Removes Skunk Odor
- Watering Solutions
VII. Peroxide Based Disinfectants: Microbicidal Activity

Historically:

Hydrogen Peroxide was not used for hard surface disinfection because:

- $\text{H}_2\text{O}_2$ is not stable, decomposes very easily, light sensitive
- Required high concentrations and/or long contact times (3%; 75 min)

Recently:

- Stabilizers identified that minimize decomposition
- “Inert” ingredients identified to boost efficacy
VII. Peroxide Based Disinfectants: How Peroxide Works

The antimicrobial properties of hydrogen peroxide result from the **non-specific** oxidation of essential cell components by atom or electron transfer.

**What does an Oxidative Mechanism look like?**

But … $\text{H}_2\text{O}_2$ is not very fast or stable when used by itself.

**Peroxide alone is NOT enough!**
VII. Peroxide Based Disinfectants: How Peroxide Works

Modern H₂O₂ Disinfectants:
Rapid antimicrobial activity against the major classes of pathogens
- Depends on concentration & formulation of product
- Typically Bactericidal, Virucidal, Fungicidal
- Peroxide Disinfectants may be Sporicidal for specific spores – at high concentrations/contact times or with odiferous additives

More Environmentally Friendly Active
- H₂O₂ decomposes into O₂ and H₂O
- Readily degradable active & components
- No VOCs (volatile organic compounds), no NPEs (nonylphenol ethoxylates) or APEs (alkylphenol ethoxylates)

Designed for Better Staff Experience and Aesthetics
- General material compatibility
- Odorless/pleasant odor, ready-to-use, non-staining products
- 12-24 month shelf life
# VII. Peroxide Based Disinfectants: Properties

<table>
<thead>
<tr>
<th>Modern HOOH Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>Broad spectrum efficacy -- bactericidal (including TB), virucidal, fungicidal</td>
<td>Additives or high concentrations needed to impart efficacy for <em>C. difficile</em></td>
</tr>
<tr>
<td>Rapid contact time</td>
<td>May contain peracetic acid which is corrosive and very odiferous</td>
</tr>
<tr>
<td>Can remove bio-films</td>
<td>Compatibility Issues with soft metals and some plastics</td>
</tr>
<tr>
<td>Low toxicity, VOC free, More environmentally friendly</td>
<td>Residue can be left on surface</td>
</tr>
<tr>
<td>Can be formulated with Cleaning agents</td>
<td></td>
</tr>
<tr>
<td>Non-Staining</td>
<td></td>
</tr>
<tr>
<td>Light Fragranced/No Strong Odor</td>
<td></td>
</tr>
<tr>
<td>Non-bleach oxidative option</td>
<td></td>
</tr>
</tbody>
</table>
### VIII. Technology Comparisons

<table>
<thead>
<tr>
<th>What?</th>
<th>QUAT Based Disinfectants</th>
<th>Alcohol Disinfectants (EtOH, IPA)</th>
<th>NaOCl Based “1:10” Disinfectants</th>
<th>Hydrogen Peroxide Disinfectants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface active agents – act on cellular membranes. Exhibit increased variability in effectiveness by organism type and Quat used.</td>
<td>Organic solvents – act on cellular membranes and denaturation of proteins. Efficacy is dependent on alcohol concentration and additives</td>
<td>Strong oxidizing activity – based on Hypochlorite anion (OCl⁻) and Hypochlorous Acid (HOCl)</td>
<td>Strong oxidizing activity – based on atom or electron transfer, hypothesized to be hydroxyl free radical, but it has not been fully elucidated.</td>
<td></td>
</tr>
<tr>
<td>Must cross the microbe’s cell membrane to inactivate it. Cell membranes vary by organism type and can inhibit the effects of QACs.</td>
<td>Alters physical properties, denatures proteins and rupture cell walls.</td>
<td>Reacts with enzymes, amino acids &amp; proteins.</td>
<td>Attacks membrane lipids, DNA, and other essential cell components.</td>
<td></td>
</tr>
<tr>
<td>Sporicidal?</td>
<td>Not proven effective against spores.</td>
<td>Not proven effective against spores.</td>
<td>Dependent upon: 1. pH 2. Concentration</td>
<td>Only when: 1. present in high concentrations and/or with long contact times 2. when harsh additives are included in the formulation.</td>
</tr>
</tbody>
</table>
IX. Choosing a Disinfectant

- Product Classification -- *Is it a Health Canada Registered Hospital Disinfectant?*
- Active Ingredient
- Efficacy Claims
- Directions for Use
- Differentiating Features
- Precautionary Statements/Safety Profile
- Health Canada/PIDAC/PHAC or other EPA/OSHA/APIC Guidelines

Look for DIN # (8 digit number)
X. Summary

Take Home Message:
Healthcare surfaces contaminated with persistent pathogens can serve as sources for transmission, which may increase the risk of spreading infections.

→ Intervention is Required

Routine **Surface Disinfection** is vital to keeping surfaces free of microorganisms and reducing the occurrence of healthcare-associated infections

Make sure that the product you choose is designed for the job that you need it to do!
Part IX. Q&A