The Future of Disinfection

Ellen Meyer
Innovative Water Care

World Aquatic Health Conference
Williamsburg VA

October 18, 2019
The Future of Disinfection

- The past
  - Case studies
  - Outbreak summary

- The future
  - Prevention of chlorine gassing
  - New approaches to pathogens
    - Optimizing traditional disinfectants
    - CYA
    - Minimizing chlorine demand and disinfection by-product (DBP) precursors
  - Non-traditional treatments

- Ultimate goal
Codes and Standards

- The Centers for Disease Control and Prevention (CDC) Model Aquatic Health Code (MAHC)
  - [https://www.cdc.gov/mahc/editions/index.html](https://www.cdc.gov/mahc/editions/index.html)

- Pool and Hot Tub Alliance (PHTA)
  - PHTA formed recently from two organizations
    - Association of Pool and Spa Professionals (APSP)- standards
    - National Swimming Pool Foundation (NSPF)- Certified Pool Operator (CPO) program

- Environmental Protection Agency (EPA)
  - Registration of products that kill and/or mitigate organisms
    - Sanitizers
    - Algaecides

- Deutsches Institut für Normung (DIN) German Institute for Standardisation
  - DIN 19643-1 Treatment of water of swimming pools and baths- Part 1: General requirements
  - DIN 19643-2 Treatment of water of swimming pools and baths- Part 2: Combinations of process with fixed bed filters and precoat filters
Outbreak Case Studies

**E. Coli O157:H7**
- Water Park, GA 1998 (Barwick 2000)
  - 26 people ill, 7 developed hemolytic uremic syndrome, 1 death
  - Fecal accident in children’s pool
  - Low chlorine levels documented

**Cryptosporidium**
- State Park Interactive Fountain, NY, June - August 2005 (Yoder 2008)
  - 2,307 ill
  - Results from outbreak
    - $5 million class action law suit
    - NY state requirement for secondary treatment of spray pads
Chlorine Gas Incident Case Studies

- Outdoor municipal water park, CA (Wilken 2017)
  - Chemical controller interlock failure
  - Bleach (NaOCl) + muriatic acid (HCl) → chlorine gas (Cl₂)
  - Staff turned off chemical overfeed alarm
  - 34 experienced vomiting, coughing or eye irritation
  - 17 transported to hospital, one remained overnight

- California 2008-2015 (Wilken 2017)
  - 9 incidents
  - 9/9 Chemical feed continued without main recirculation flow
  - 7/9 Main flow resumed while bathers were present
  - 155 Symptomatic, 121 medical attention, 5+ hospitalized
# Disease Outbreaks for Treated Recreational Water

Reported by CDC: 2013-2014 (Hlavsa 2018)

- 71 Outbreaks
- 963 People ill
- 94 Hospitalized

<table>
<thead>
<tr>
<th>Group</th>
<th>Species</th>
<th>Outbreaks</th>
<th>Cases</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td></td>
<td>13</td>
<td>262</td>
<td>10</td>
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<tr>
<td>Bacteria</td>
<td><em>Pseudomonas aeruginosa</em></td>
<td>4</td>
<td>12</td>
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<tr>
<td></td>
<td><em>Salmonella</em></td>
<td>1</td>
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<tr>
<td></td>
<td><em>Shigella sonnei</em></td>
<td>1</td>
<td>6</td>
<td>0</td>
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<tr>
<td></td>
<td><em>Mycobacterium abscessus</em></td>
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<td>11</td>
<td>0</td>
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<tr>
<td></td>
<td><em>Legionella spp.</em></td>
<td>18</td>
<td>72</td>
<td>36</td>
</tr>
<tr>
<td>Parasites</td>
<td><em>Cryptosporidium spp.</em></td>
<td>29</td>
<td>543</td>
<td>44</td>
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<td></td>
<td><em>Giardia</em></td>
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<td>3</td>
<td>0</td>
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<tr>
<td>Viruses</td>
<td>Norovirus</td>
<td>2</td>
<td>34</td>
<td>0</td>
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<tr>
<td>Unknown</td>
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<td>1</td>
<td>15</td>
<td>2</td>
</tr>
</tbody>
</table>
American Chemistry Council (ACC)
  o Chemical safety videos  https://chlorine.americanchemistry.com/Pool-Chemical-Safety-Resources/
    ▪ Preventing unintended chemical injection
Preventing Unintended Chemical Injection

Used with permission from the American Chemistry Council
Preventing Unintended Chemical Injection

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* FOR ILLUSTRATION PURPOSES ONLY!
Size of pipes, location of injectors, amount of water in the pipes
and amount of chemicals are not to scale.
Preventing Unintended Chemical Injection

Used with permission from the American Chemistry Council

*FOR ILLUSTRATION PURPOSES ONLY! Size of pipes, location of injectors, amount of water in the pipes and amount of chemicals are not to scale.
Chemical Feed Interlocks and Actions

- Feeders and controllers for disinfection and pH chemicals (MAHC 4.7.3.2.1)
  - Must be listed to NSF/ANSI-50 (4.7.3.2.1.2)
  - Must have at least two interlocks (4.7.3.2.1.3)
    - Recirculation pump power monitor
    - Flow meter/flow switch in return line
    - Flow meter/flow switch at chemical controller
  - Must have visual alarm if interlock activated*

- Policies (MAHC 5.7.3.5)
  - Bathers evacuated if interlock activated or recirculation pump is off*
  - No start-up until manual evaluation by responsible supervisor or qualified operator*
  - Bather re-entry ≥ 5 minutes after system start-up*

* New in 2018 MAHC
Venturi Feeders

Old concept*, new perspective

Low pressure region pulls chemical into Venturi

Water Flow

High pressure

Low pressure

*Giovanni Battista Venturi 1746-1822
Old concept, new perspective

- Chemicals are pulled into the pipe, not pushed
- Chemical feed stops when the flow stops
- Does not rely on interlocks that can fail

Future technologies could make use of old concepts in new ways.
There is no perfect sanitizer:
- Kills all pathogens within seconds
- Has no toxicity to humans at use concentrations
- Has a stable residual
- Can be measured with pool-side test kits
- Produces no disinfection byproducts
- Economical

So what do we do?
- Keep looking for the Holy Grail
- Keep looking for multi-pronged approaches to optimize sanitation and minimize issues
# Recreational Water Pathogens

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Source</th>
<th>Illness</th>
<th>Reproduction</th>
<th>Typical* Free Chlorine (FC) CT</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudomonas</em></td>
<td>People and Environment</td>
<td>Rash</td>
<td>In water/biofilm</td>
<td>&lt;1 ppm min</td>
</tr>
<tr>
<td><em>Legionella</em></td>
<td>Environment</td>
<td>Pontiac fever or pneumonia</td>
<td>In water/biofilm</td>
<td>4 ppm min</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>People</td>
<td>Diarrhea</td>
<td>In people</td>
<td>&lt;1 ppm min</td>
</tr>
<tr>
<td><em>Shigella</em></td>
<td>People</td>
<td>Diarrhea</td>
<td>In people</td>
<td>3 ppm min</td>
</tr>
<tr>
<td>Norovirus</td>
<td>People</td>
<td>Diarrhea</td>
<td>In people</td>
<td>~45 ppm min</td>
</tr>
<tr>
<td>Giardia</td>
<td>People</td>
<td>Diarrhea</td>
<td>In people</td>
<td>~45 ppm min</td>
</tr>
<tr>
<td><em>Cryptosporidium</em></td>
<td>People</td>
<td>Diarrhea</td>
<td>In people</td>
<td>15,300 ppm min</td>
</tr>
</tbody>
</table>

* Typical CT values will be higher in the presence of cyanuric acid (CYA).
## Bather Load Statistics

<table>
<thead>
<tr>
<th>Grams of feces added to water per person</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Child</td>
<td>0.01 - 10</td>
</tr>
<tr>
<td>Adult</td>
<td>0.0001 – 0.1</td>
</tr>
<tr>
<td>Mean</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Source: Gerba 2000

<table>
<thead>
<tr>
<th>Pool size, gallons</th>
<th>Gallons of urine per pool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool 1</td>
<td>110,000</td>
</tr>
<tr>
<td>Pool 2</td>
<td>220,000</td>
</tr>
</tbody>
</table>

Source: Blackstock 2017
Contamination Prevention

- Contamination is inevitable
  - Bacteria from environment
  - Bacteria, viruses and protozoa from people

- Contamination can be minimized
  - Bather hygiene
  - Shower before swimming
  - Do not swim if ill with diarrhea
  - Frequent bathroom breaks
  - Diaper changing stations

- Social science innovations
Primary Sanitizers

<table>
<thead>
<tr>
<th></th>
<th>EPA Registered</th>
<th>Accepted in PHTA-11</th>
<th>Accepted in MAHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Bromine</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PHMB (biguanide)</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Some metal systems</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Maintain an EPA registered sanitizer residual
in all parts of the pool – at all times
## Chlorine

### Current Limits

<table>
<thead>
<tr>
<th></th>
<th>EPA labels</th>
<th>PHTA-11</th>
<th>MAHC*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pools, no CYA, FC ppm</td>
<td>1-4</td>
<td>1-4</td>
<td>1-10</td>
</tr>
<tr>
<td>Pools, with CYA, FC ppm</td>
<td>1-4</td>
<td>2-4 if CYA&gt;50 ppm</td>
<td>2-10</td>
</tr>
<tr>
<td>Spas, FC ppm</td>
<td>2-5</td>
<td>2-5 (0-50 ppm CYA)</td>
<td>3-10 (0 ppm CYA)</td>
</tr>
</tbody>
</table>

*MAHC FC Maximum = 10 ppm, but follow label
No EPA labels allow >4 ppm FC for pools and >5 ppm FC for spas
Chlorine

Effect of pH on HOCl

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

HOCl is the active sanitizer in pools

<table>
<thead>
<tr>
<th>pH</th>
<th>%HOCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>99.7%</td>
</tr>
<tr>
<td>7.0</td>
<td>77.5%</td>
</tr>
<tr>
<td>7.5</td>
<td>52.2%</td>
</tr>
<tr>
<td>8.0</td>
<td>25.7%</td>
</tr>
<tr>
<td>9.5</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

HOCl Hypochlorous acid
OCl$^-$ Hypochlorite ion
H$^+$ Hydrogen ion
Chlorine

Effect of CYA on HOCl

pH 7.5, 85 °F, 800 ppm TDS

<table>
<thead>
<tr>
<th>CYA, ppm</th>
<th>%HOCl for 1 ppm FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>47%</td>
</tr>
<tr>
<td>5</td>
<td>13%</td>
</tr>
<tr>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>20</td>
<td>3%</td>
</tr>
<tr>
<td>50</td>
<td>1%</td>
</tr>
</tbody>
</table>

Equilibrium constants from O’Brien 1972
Cyanuric Acid

Effect of CYA on Probability of Infection

- CYA Ad Hoc Committee
- Risk Calculations
  - Ingestion only
  - Routine fecal sloughing only
- Open access model published June 2019 (Falk 2019)

CYA raises the risk of infection
The Future is to Focus on HOCl
Remedial and continuous treatment in the presence of CYA

- If the CYA:FC ratio is constant, the HOCl concentration is constant (Falk 2019)
- The CYA ad hoc committee is recommending a ratio of 20:1
- So for a 20:1 ratio, the HOCl is ~ 0.02 ppm

Using a 20:1 ratio of CYA:FC

<table>
<thead>
<tr>
<th>FC, ppm</th>
<th>CYA, ppm</th>
<th>HOCl, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.01962</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>0.02006</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.02021</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>0.02029</td>
</tr>
</tbody>
</table>
Cyanuric Acid

How do you operate off of a ratio?

Using the 20:1 CYA:FC ratio and EPA limits

<table>
<thead>
<tr>
<th>CYA, ppm</th>
<th>FC Control Range (EPA max limit)</th>
<th>FC Control Range (CDC max limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>1 ppm min – 4 ppm max</td>
<td>1-10</td>
</tr>
<tr>
<td>21-40</td>
<td>2 ppm min – 4 ppm max</td>
<td>2-10</td>
</tr>
<tr>
<td>41-60</td>
<td>3 ppm min – 4 ppm max</td>
<td>3-10</td>
</tr>
<tr>
<td>61-80</td>
<td>4 ppm min – 4 ppm max</td>
<td>4-10</td>
</tr>
</tbody>
</table>

- It is a violation of federal law to use a chlorine sanitizer in a manner inconsistent with its labeling.
Cyanuric Acid

How do you operate a pool using a ratio? Analysis example

- Measure free chlorine (FC)
- Measure cyanuric acid (CYA)

- If FC < CYA/20, there is a non-compliance
- If FC < CYA x 0.05 there is a non compliance \[(1/20 = 0.05)\]

Example
- FC = 3.5 ppm
- CYA = 80 ppm

- CYA/20 = 80/20 = 4.0 ppm minimum FC
- CYA x 0.05 = 80 x 0.05 = 4.0 ppm minimum FC

- 3.5 < 4.0, so there is a non-compliance
## Cyanuric Acid

### How do you operate a pool using a ratio? Log sheet example

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Time</th>
<th>Initials</th>
<th>Total Cl, ppm</th>
<th>Free Cl, ppm</th>
<th>Combined Cl, ppm</th>
<th>pH</th>
<th>Flow rate, gpm</th>
<th>Temp, °F</th>
<th>CYA, ppm</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/1/2019</td>
<td>Saturday</td>
<td>10:00</td>
<td>EMM</td>
<td>4.0</td>
<td>4.0</td>
<td>0.0</td>
<td>7.6</td>
<td>100</td>
<td></td>
<td>84</td>
<td>20</td>
</tr>
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<td>7.6</td>
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<td>Swim meet</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>18:00</td>
<td>EMM</td>
<td>1.9</td>
<td>1.4</td>
<td>0.5</td>
<td>7.5</td>
<td>100</td>
<td>86</td>
<td></td>
<td>1.5</td>
</tr>
</tbody>
</table>
Picking a CYA Concentration

- Pool A is able to maintain chlorine levels between 1 and 4 ppm.
  - CYA concentrations need to be between 0 and 20 ppm
- Pool B is able to maintain chlorine levels between 2 and 4 ppm.
  - CYA concentrations need to be between 0 and 40 ppm
Control additions of CYA

- **Stabilized sanitizer tablets**
  - Trichloroisocyanuric acid slow dissolving tablets
  - Primary advantage is convenience
  - Lack of maintenance attention may lead to exceeding CYA limits

- **Unstabilized sanitizer tablets**
  - New slow dissolve calcium hypochlorite tablets
  - Slow dissolve tablet convenience
  - No CYA contribution

Cyanuric Acid

\( \text{Ca(OCl)}_2 \)
Other ways to optimize pool sanitation

- Reduce chlorine demand and DBP precursors
  - Bather hygiene and bather load
  - Better filtration
  - Water replacement
  - Flocculation

- Additional treatments for reducing pathogens and DBPs
  - UV
  - Ozone
  - Radicals/AOP
  - Chlorine dioxide
  - Filtration
  - Dilution
WAHC / DIN Comparison

(Referenced section in 2018 MAHC, DIN 19643-1:2012-11)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MAHC</th>
<th>DIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bather load maximum, sqft/bather</td>
<td>20 for “flat water” ([4.1.2.3.5.3])</td>
<td>48 for swimming pools (Table 3)</td>
</tr>
<tr>
<td>Turnover maximum, hours</td>
<td>6 for “all other pools” ([4.7.1.10])</td>
<td>2.25 for 3.3 ft (1 M) deep swimming pool with fixed bed filter (Table 3)</td>
</tr>
<tr>
<td>Free chlorine for pools, ppm</td>
<td>1 ppm minimum, label maximum (EPA 4 ppm) ([5.7.3.1.1])</td>
<td>0.3 – 1.2 ppm ([11.2.1])</td>
</tr>
<tr>
<td>CYA maximum, ppm</td>
<td>90 ppm ([5.7.3.1.3.2])</td>
<td>No stabilized sanitizers allowed ([11.2.2])</td>
</tr>
<tr>
<td>Water replacement minimum, gal/bather/day</td>
<td>4 ([5.6.7.4])</td>
<td>7.9 (30 L) ([13.5])</td>
</tr>
<tr>
<td>Flocculation</td>
<td>Not required</td>
<td>Required for fixed bed filters (DIN 19643-2 4.3)</td>
</tr>
<tr>
<td>Sand bed height minimum, inches</td>
<td>15 ([5.7.2.2.1])</td>
<td>47 for closed and 35 for open rapid filters (DIN 19643-2 4.4.2.1)</td>
</tr>
<tr>
<td>Sand filter loading maximum, gpm/sqft</td>
<td>15 ([5.7.2.2.1])</td>
<td>12 for closed and 5 for open rapid filters (DIN 19643-2 4.4.2.1)</td>
</tr>
</tbody>
</table>
Secondary Disinfection

MAHC 4.7.3.3 and PHTA/ANSI-11 Require UV or ozone for

- Aquatic venues designed primarily for children under 5 years old
  - Wading pools
  - Interactive water play venues with no standing water
- Therapy pools

- UV and ozone are effective against crypto

MAHC A 4.7.3.3
Strongly recommended for all aquatic facilities
UV Issues and Interferences

EPA 815-R-06-007 Ultraviolet disinfection guidance manual for the final long term 2 enhanced surface water treatment rule, 2006.

Issues

- Need dose verification (initial and ongoing with age)
- Mercury contamination from lamp breakage
  - Appendix E EPA 815-R-06-007
- Effect on Disinfection By-Products (DBP’s) (Weng 2012)
  - Decrease in inorganic chloramines
  - Increase in some organic chloramines in presence of chlorine
    - Dichloromethylamine, dichloroacetonitrile, cyanogen chloride
UV Issues and Interferences

Interferences

- Humic substances, algae
- Turbidity
- Fouling (scale)

EPA 815-R-06-007, Table 2.5

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molar Absorption Coefficient (M⁻¹ cm⁻¹)</th>
<th>Impact Threshold Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>3,250</td>
<td>0.071</td>
</tr>
<tr>
<td>Ferric iron (Fe³⁺)</td>
<td>4,716</td>
<td>0.057</td>
</tr>
<tr>
<td>Permanganage (MnO₄⁻)</td>
<td>657</td>
<td>0.91</td>
</tr>
<tr>
<td>Hypochlorite (OCl⁻)</td>
<td>29.5</td>
<td>8.4</td>
</tr>
<tr>
<td>Hydrogen peroxide (H₂O₂)</td>
<td>18.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Ferrous iron (Fe²⁺)</td>
<td>28</td>
<td>9.6</td>
</tr>
<tr>
<td>Zinc (Zn²⁺)</td>
<td>1.7</td>
<td>187</td>
</tr>
</tbody>
</table>
Ozone Issues and Interferences

Issues
- Ozone exposure
  - 0.1 ppm maximum in air over water (MAHC 4.7.3.3.4.9)
  - Degas and ozone destruct required (MAHC 4.7.3.3.4.4)
- Formation of DBP’s (EPA 815-RR-99-014)
  - No Cl, Br present
    - Aldehydes, acids
  - With Cl, Br present
    - Bromate, brominated organics
      - Not recommended for use with bromine (MAHC A 5.7.3.1.2)
    - Chloral hydrate, chloropicrin

Interferences
- Ozone demand from other oxidizable substances
  - May reduce chlorine demand
Secondary Disinfection

UV and Ozone Challenges

- UV and ozone do not have a residual throughout the pool
- Inactivation of organisms is only occurring in the pipe
- They cannot be used for primary disinfection
- You must have a primary disinfectant residual in all parts of the pool at all times
Radical Treatment

Advanced Oxidation Processes (AOPs)

Radicals in chemistry

- Unpaired electrons are typically unstable
  - Water (H₂O) is very stable, no unpaired electrons
  - Hydroxyl radicals (HO·) are not stable

- Difficult to measure HO· directly (e.g. emission spectroscopy)

- Can measure HO· in water by reaction with specific chemicals (e.g. terephthalic acid conversion to hydroxyterephthalic acid, Sahni 2006)

- HO· can be produced in various ways, including
  - UV + ozone, H₂O₂ + ozone, UV + H₂O₂
  - Electrochemically
  - UV + Magnetic flux (no peer reviewed literature)

- Other radicals
  - Oxygen radical
  - Chlorine dioxide
**Hydroxyl Radicals**

- Hydroxyl radicals will react with just about anything, including:
  - Organic contaminants
  - Carbonate and bicarbonate
  - Themselves \((\text{OH} \cdot + \text{OH} \cdot \rightarrow \text{H}_2\text{O}_2)\)
  - Hydrogen peroxide \((\text{H}_2\text{O}_2)\)

<table>
<thead>
<tr>
<th></th>
<th>Oxidation potential, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxyl radical ((\text{OH} \cdot))</td>
<td>2.80</td>
</tr>
<tr>
<td>Ozone ((\text{O}_3))</td>
<td>2.07</td>
</tr>
<tr>
<td>Chlorine dioxide ((\text{ClO}_2))</td>
<td>1.50</td>
</tr>
<tr>
<td>Chlorine ((\text{Cl}_2))</td>
<td>1.36</td>
</tr>
</tbody>
</table>

- Efficiency of hydroxyl radical production, destruction and activity will vary with:
  - pH
  - Ratio of components in the water \(\text{O}_3, \text{H}_2\text{O}_2, \text{UV}\)
  - Reactants (see above)
Hydroxyl Radical Disinfection

- EPA Drinking water rules
  - No disinfection credit for OH· because no residual can be measured.
  - Disinfection credits available for precursor O₃ if residual is present.

Hydroxyl Radical Conclusions

- Hydroxyl radicals can be very effective
- For any production method:
  - Except in tightly controlled lab conditions hard to measure OH· and confirm activity is from OH· and not from precursors
  - In a field trial setting, nearly impossible to prove activity is from OH·
  - For evaluation of any commercial unit, a carefully controlled field trial may at least determine if there is an advantage to switching from current treatment
Chlorine Dioxide

Stable Radical

- Chlorine dioxide (ClO₂) is a radical
- ClO₂ is more stable and is capable of maintaining a residual
- ClO₂ can be measured with pool-side test kits
- CT values for ClO₂ have been reported

<table>
<thead>
<tr>
<th>Viruses  (EPA 1999)</th>
<th>4.3</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Giardia</em> (EPA 1999)</td>
<td>11.0</td>
</tr>
<tr>
<td><em>Cryptosporidium</em> (Murphy 2014)</td>
<td>640</td>
</tr>
</tbody>
</table>
ClO₂ Disinfection - Biofilm (Gagnon 2004)

Heterotrophic Plate Count (HPC) Reductions
Polycarbonate (PC) and Cast Iron (CI) Coupons

Bulk water HPC (PC)  Bulk water HPC (CI)  Biofilm HPC (PC)  Biofilm HPC (CI)

Log Reduction
**ClO₂ Properties**

- ClO₂ has a lower redox potential than ozone or chlorine
  - Greater penetration of biofilm
  - Fewer reactions with oxidizable water system components

- ClO₂ reaction end-products (EPA 1999)

<table>
<thead>
<tr>
<th></th>
<th>End-product, %</th>
<th>EPA Limits</th>
<th>WHO Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClO₂</td>
<td></td>
<td>MRDL = 0.8 mg/L</td>
<td></td>
</tr>
<tr>
<td>Chlorite (ClO₂⁻)</td>
<td>50-70%</td>
<td>MCL = 1.0 mg/L</td>
<td>0.7 mg/L</td>
</tr>
<tr>
<td>Chlorate (ClO₃⁻)</td>
<td>30% (ClO₃⁻ + Cl⁻)</td>
<td></td>
<td>0.7 mg/L</td>
</tr>
</tbody>
</table>

MRDL = Maximum residual disinfectant limit
MCL = Maximum contaminant level
ClO₂ Generation

- **ClO₂ safety concerns**
  - Explosive gas at concentrations > 10% (Masschelein 1979)
  - Solutions can be made, but ClO₂ gas may accumulate in headspace of containers
    - Partition coefficients in water (Masschelein 1979)

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>ClO₂(aq) / ClO₂(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>70 +/- 0.7</td>
</tr>
<tr>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td>35</td>
<td>26.5 +/- 0.8</td>
</tr>
</tbody>
</table>

- **On-site generation typically used**
  - Precursor chemical activated on-site
  - On-site electrochemical generation
**ClO₂ Generation**

**Chemical**
- From sodium chlorite (NaClO₂)
  - 2NaClO₂ + Cl₂ → 2ClO₂ + 2NaCl
  - 2NaClO₂ + HOCl → 2ClO₂ + NaCl + NaOH
  - 5NaClO₂ + 4HCl → 4ClO₂ + 5NaCl + 2H₂O
- From sodium chlorate (NaClO₃)
  - 2NaClO₃ + SO₂ + H₂SO₄ → 2ClO₂ + + 2NaHSO₄

**Electrochemical**
- NaClO₂ → ClO₂ + Na⁺ + e⁻
### Filtration for Crypto Removal

**Cryptosporidium Surrogate Removals**

<table>
<thead>
<tr>
<th>Filter Media</th>
<th>Log Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartridge</td>
<td>0.19</td>
</tr>
<tr>
<td>Sand</td>
<td>0.16</td>
</tr>
<tr>
<td>Diatomaceous Earth</td>
<td>2.35</td>
</tr>
<tr>
<td>Perlite - Fine</td>
<td>3.23</td>
</tr>
<tr>
<td>Diatomaceous Earth – Fine</td>
<td>4.33</td>
</tr>
<tr>
<td>Coagulant + Sand</td>
<td>0.41 (*continuous dose 2.0-2.5)</td>
</tr>
<tr>
<td>Coagulant + Sand full scale pool</td>
<td>1-2**</td>
</tr>
</tbody>
</table>

Amburgey 2012,  
*Lu 2012,  
**Amburgey from pwtag.org
Gage-Bidwell Dilution

Gage-Bidwell: This is the best you can get for in-pipe treatment

- Perfect mixing
- Treatment of full flow
- Log removal in pool using treatments
  - With 0.15-log, 1-log, 2-log, 3-log and perfect (∞-log) removals in the pipe

<table>
<thead>
<tr>
<th>Turnovers</th>
<th>0.15-log</th>
<th>1-log</th>
<th>2-log</th>
<th>3-log</th>
<th>∞-log</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.13</td>
<td>0.39</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>0.26</td>
<td>0.78</td>
<td>0.86</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>1.2</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>0.9</td>
<td>2.7</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Log Removal = Log(e^{rt})

r = efficiency of unit
t = turnovers
MAHC Secondary Disinfection

- Changes in 2018 MAHC 4.7.3.3.2.1
  - 3-log reduction required for interactive water play venues with no standing water
  - New: 2-log reduction required for wading pools and therapy pools

- NSF Filtration Committee developing a test protocol for crypto removal with filters
  - Issues
    - Lab performance vs field performance
    - Verification
Lagoons, Surf Parks and Other Big Water

- Which has greater risk?
  - 100,000 gallon pool with 50 bathers treated with 1 ppm chlorine
  - 10,000,000 gallon pool with 5 bathers and no treatment

- Factors to consider
  - Dilution
  - Proximity of bathers
  - Dilution is equally effective for all pathogens that don’t reproduce in the water, but not effective for pathogens that can reproduce in the water
  - Disinfectants have variable efficacy
  - Practicality of maintaining a residual throughout Big Water, continuously
  - Pathogen die-off from natural causes

- Possible control measures
  - Treat Big Water like traditional pools
  - Limit bather load
  - Signage indicating lack of water treatment, like beaches
  - Limit swimming to areas that are treated like traditional pools
FLL 2011 Recommendations for planning, construction, servicing and operating of outdoor swimming pools with biological water purification

- **Temperature (FLL 4.2)**
  - Maximum 28 °C (82.4 °F)
  - >25 °C (77 °F) for no more than five days

- **Bather load (FLL 5.1.1)**
  - Minimum 925 gallons (3.5 m³)/person/day
  - 10.8 people per day per 10,000 gallons

- **Depth of transparency (FLL 4.2)**
  - Minimum 1.80 m (5.9 ft)

- **Microbiological parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. coli</em>, cfu/100 ml</td>
<td>≤ 100</td>
</tr>
<tr>
<td>Enterococci, cfu/100 ml</td>
<td>≤ 50</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em>, cfu/100 ml</td>
<td>≤ 10</td>
</tr>
<tr>
<td><em>Legionella</em>, organisms/100 ml</td>
<td>none</td>
</tr>
</tbody>
</table>
The Future of Disinfection

- Multi-pronged approaches needed to
  - Prevent chemical injury
  - Prevent recreational water illness
  - Prevent DBP formation

- Policies and Procedures
  - Clear pool when pump stops
  - Reduced bather load (hygiene and bather limits)

- Physical processes
  - Venturis, interlocks, and alarms
  - Enhanced water treatment
    - Circulation
    - Filtration

- Chemical processes
  - Optimize traditional sanitizers
    - CYA
    - Flocculation to remove Cl-demand and DBP precursor
  - UV
  - Ozone
  - Hydroxyl radicals
  - Chlorine dioxide
CDC’s Healthy Swimming website identifies the following benefits of water-based activity:

- The benefits of water-based activity outweigh the risks of illness and injury.
- Water-based exercise can help people with **chronic diseases**, such as **arthritis**.
- Water-based exercise puts little or no stress on joints. In arthritis patients, it improves use of affected joints.
- Water-based exercise improves **mental health**—for example it decreases depression and improves mood.
- Water-based exercise can benefit older adults by improving the **quality of life** and **decreasing disability**.
- Water-based exercise can improve or maintain the **bone health** of post-menopausal women.
- Swimming can be a great way to get and **stay fit during pregnancy**.
Public Health and Recreational Water

The benefits of water-based activity outweigh the risks of illness and injury.

- Disease Outbreaks for Treated Recreational Water 2013-2014 (Hlavsa 2018)
  - 71 Outbreaks
  - 963 People ill
  - 94 Hospitalized

- U.S. Mortality Statistics for 2017 (Heron 2019)

<table>
<thead>
<tr>
<th>Cause</th>
<th>45-54 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diseases of the heart</td>
<td>32,658</td>
</tr>
<tr>
<td>Intentional self-harm</td>
<td>8,561</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>6,409</td>
</tr>
<tr>
<td>Cerebrovascular diseases</td>
<td>5,198</td>
</tr>
</tbody>
</table>

- Two ultimate goals
  - Healthy lifestyles
  - Healthy pools
Sources and References

- Centers for Disease Control and Prevention (CDC).
  - [http://www.cdc.gov/healthyswimming/](http://www.cdc.gov/healthyswimming/)

- Pool and Hot Tub Alliance (PHTA).
  - Information Bulletins on Pathogens, Contamination Response and Sanitizers.
  - Standards.
  - [http://www.apsp.org](http://www.apsp.org)

- Environmental Protection Agency (EPA).
  - EPA Registrations.
    - Label images. [http://oaspub.epa.gov/pestlabl/ppls.home](http://oaspub.epa.gov/pestlabl/ppls.home)
Sources and References

- Deutsches Institut für Normung (DIN) German Institute for Standardisation
  - DIN 19643-1 Treatment of water of swimming pools and baths- Part 1: General requirements
  - DIN 19643-2 Treatment of water of swimming pools and baths- Part 2: Combinations of process with fixed bed filters and precoat filters

- Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V. (FLL)
  - Recommendations for Planning, construction, servicing and operating of outdoor swimming pools with biological water purification (Swimming and bathing ponds), August 2011.

- World Health Organization Guidelines.


Sources and Reference

THANK YOU
Contact: Ellen.Meyer@Lonza.com