DEZINFEKCIJA VODE ZA PIĆE

Siniša L. Markov, Dragoljub D. Cvetković, Aleksandra S. Velićanski
60% of your body

70% of your brain

While you can go almost a month without food...

your body can’t survive one week without water.
The same water that existed on Earth billions of years ago still exists today.

It covers most of the planet, but just 3% is freshwater.

Less than 1% of all freshwater is readily accessible for human use.

Less than 0.007% of all the water on Earth is available to drink.
Science and technology for water purification in the coming decades
Mark A. Shannon, Paul W. Bohn, Menachem Elimelech, John G. Georgiadis, Benito J. Mariñas & Anne M. Mayes

Abstract
One of the most pervasive problems afflicting people throughout the world is inadequate access to clean water and sanitation. Problems with water are expected to grow worse in the coming decades, with water scarcity occurring globally, even in regions currently considered water-rich. Addressing these problems calls out for a tremendous amount of research to be conducted to identify robust new methods of purifying water at lower cost and with less energy, while at the same time minimizing the use of chemicals and impact on the environment. Here we highlight some of the science and technology being developed to improve the disinfection and decontamination of water, as well as efforts to increase water supplies through the safe re-use of wastewater and efficient desalination of sea and brackish water.
kome još – pa poželjno je .....
\[
\ln\left(\frac{N_t}{N_0}\right) = -\lambda C t
\]

where,
- \(N_0\) = initial number of organisms
- \(N_t\) = number of organisms at time \(t\)
- \(C\) = concentration of disinfectant (mg/L)
- \(t\) = contact time (min)
- \(\lambda\) = coefficient of specific lethality
- \(n\) = coefficient depending on disinfectant type and pH

TEM mikrografija
CT-values for the inactivation of *Giardia* cysts by various disinfectants

<table>
<thead>
<tr>
<th>Disinfectant</th>
<th>Inactivation (mg · min/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5-log</td>
</tr>
<tr>
<td>Chlorine&lt;sup&gt;1&lt;/sup&gt;</td>
<td>17</td>
</tr>
<tr>
<td>Chloramine&lt;sup&gt;2&lt;/sup&gt;</td>
<td>310</td>
</tr>
<tr>
<td>Chlorine Dioxide&lt;sup&gt;3&lt;/sup&gt;</td>
<td>4</td>
</tr>
<tr>
<td>Ozone&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.23</td>
</tr>
</tbody>
</table>

CT values were obtained from AWWA, 1991.

<sup>1</sup>Values are based on a free chlorine residual less than or equal to 0.4 mg/L, temperature of 10°C, and a pH of 7.

<sup>2</sup>Values are based on a temperature of 10°C and a pH in the range of 6 to 9.

<sup>3</sup>Values are based on a temperature of 10°C and a pH of 6 to 9.
Imunofluorescentna slika oocista Cryptosporidium parvum
CT-values for the inactivation of viruses by various disinfectants

<table>
<thead>
<tr>
<th>Disinfectant</th>
<th>Units</th>
<th>Inactivation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2-log</td>
</tr>
<tr>
<td>Chlorine(^1)</td>
<td>mg · min/L</td>
<td>3</td>
</tr>
<tr>
<td>Chloramine(^2)</td>
<td>mg · min/L</td>
<td>643</td>
</tr>
<tr>
<td>Chlorine Dioxide(^3)</td>
<td>mg · min/L</td>
<td>4.2</td>
</tr>
<tr>
<td>Ozone</td>
<td>mg · min/L</td>
<td>0.5</td>
</tr>
<tr>
<td>UV</td>
<td>mW · s/cm(^2)</td>
<td>21</td>
</tr>
</tbody>
</table>

CT values were obtained from AWWA, 1991.

\(^1\)Values are based on a temperature of 10°C, pH range of 6 to 9, and a free chlorine residual of 0.2 to 0.5 mg/L.

\(^2\)Values are based on a temperature of 10°C, pH of 8.

\(^3\)Values are based on a temperature of 10°C, pH range of 6 to 9.
<table>
<thead>
<tr>
<th>pH</th>
<th>Percent of active HOCl (%)</th>
<th>Percent of inactive OCI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>6.0</td>
<td>96</td>
<td>4</td>
</tr>
<tr>
<td>7.0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>7.2</td>
<td>66</td>
<td>34</td>
</tr>
<tr>
<td>7.5</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>7.8</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>8.0</td>
<td>22</td>
<td>78</td>
</tr>
</tbody>
</table>
Uporedna efikasnost dezinfektanata za 99%-nu bakterijsku inaktivaciju

<table>
<thead>
<tr>
<th>dezinfektant</th>
<th>pH</th>
<th>temperatura (°C)</th>
<th>CT (mg/min L⁻¹)</th>
<th>pH</th>
<th>temperatura (°C)</th>
<th>CT (mg/min L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hipohlorasta kiselina</td>
<td>6,0</td>
<td>5</td>
<td>0,04</td>
<td>7,0</td>
<td>1-2</td>
<td>0,08±0,02</td>
</tr>
<tr>
<td>Hipohoritni jon</td>
<td>10,0</td>
<td>5</td>
<td>0,92</td>
<td>8,5</td>
<td>1-2</td>
<td>3,3±1,0</td>
</tr>
<tr>
<td>Hlor-dioksid</td>
<td>6,5</td>
<td>20</td>
<td>0,18</td>
<td>7,0</td>
<td>1-2</td>
<td>0,13±0,02</td>
</tr>
<tr>
<td>Monohloramin</td>
<td>9,0</td>
<td>15</td>
<td>64</td>
<td>7,0</td>
<td>1-2</td>
<td>9,4±7,0</td>
</tr>
</tbody>
</table>
Procenjene CT vrednosti za inaktivaciju *Giardia* oocista slobodnim hlorom na 25°C

<table>
<thead>
<tr>
<th>Hlor (mg/L)</th>
<th>pH 7</th>
<th>pH 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Log inaktivacija</td>
<td>Log inaktivacija</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>1,6</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>2,6</td>
<td>15</td>
<td>29</td>
</tr>
</tbody>
</table>
dezinfekcija hlordioksidom
UV for drinking water
Tipične UV doze za četiri log inaktivaciju različitih mikroorganizama

<table>
<thead>
<tr>
<th>bakterije</th>
<th>doza zračenja mW-s/cm²</th>
<th>virusi</th>
<th>doza zračenja mW-s/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>spore <em>Bacillus subtilis</em></td>
<td>31</td>
<td>koksaki AZ</td>
<td>30</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>20</td>
<td>Hepatitis A</td>
<td>6 - 15</td>
</tr>
<tr>
<td><em>Salmonella typhi</em></td>
<td>30</td>
<td>Poliovirus</td>
<td>23 - 29</td>
</tr>
<tr>
<td><em>Vibrio cholera</em></td>
<td>0,65</td>
<td>Rotavirus SA11</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>adenovirus</td>
<td>186</td>
</tr>
</tbody>
</table>
Electric charge transforms oxygen into ozone:

\[ O + O_2 \rightarrow O_3 \]

Ozone creation and decomposition:

HOW DOES OZONE WORK?

OXYGEN (O\textsuperscript{2-})

HIGH VOLTAGE

ATTACKING POLLUTANTS AND KILLING GERMS

OZONE (O\textsubscript{3})

OXYGEN (O\textsuperscript{2-})
### History of GRAS Status of Ozone

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1840</td>
<td>Discovered by Schönbein</td>
</tr>
<tr>
<td>1893</td>
<td><strong>Used as a disinfectant in drinking water</strong></td>
</tr>
<tr>
<td>1909</td>
<td>Used as a food preservative for cold storage of meats</td>
</tr>
<tr>
<td>1939</td>
<td>Was found to prevent the growth of yeast &amp; mold during the storage of fruits</td>
</tr>
<tr>
<td>1982</td>
<td><strong>FDA GRAS declaration for ozone use in bottled water</strong></td>
</tr>
<tr>
<td>1995</td>
<td><strong>FDA GRAS for ozone use in bottled water renewed without change</strong></td>
</tr>
<tr>
<td>1997</td>
<td><strong>Industry Expert Panel declares ozone GRAS and meets FDA requirements. Regulators have the option to later add control on ozone use.</strong></td>
</tr>
<tr>
<td>1999</td>
<td>USDA rejects an ozone use protocol for meats, cites 1982 GRAS declaration for water where FDA stated “any other use must be regulated by a Food Additive Petition.”</td>
</tr>
<tr>
<td>2000</td>
<td>Food Additive Petition, that addresses both water and air use of ozone, under preparation. FDA estimates approval will occur within six months of submission of the Petition</td>
</tr>
</tbody>
</table>
## Oxidizing Potential of Various Reagents

<table>
<thead>
<tr>
<th>Oxidizing Reagent</th>
<th>Oxidizing Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>2.07</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
<td>1.77</td>
</tr>
<tr>
<td>Permanganate</td>
<td>1.67</td>
</tr>
<tr>
<td>Chlorine Dioxide</td>
<td>1.57</td>
</tr>
<tr>
<td>Hypochlorous Acid</td>
<td>1.49</td>
</tr>
<tr>
<td>Chlorine Gas</td>
<td>1.36</td>
</tr>
<tr>
<td>Hypobromous Acid</td>
<td>1.33</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.23</td>
</tr>
<tr>
<td>Bromine</td>
<td>1.09</td>
</tr>
<tr>
<td>Hypoiodous Acid</td>
<td>0.99</td>
</tr>
<tr>
<td>Hypochlorite</td>
<td>0.94</td>
</tr>
<tr>
<td>Chlorite</td>
<td>0.76</td>
</tr>
<tr>
<td>Iodine</td>
<td>0.54</td>
</tr>
</tbody>
</table>
Inaktivacija virusa
(2 log jedinice)

Inaktivacija cista *Giardia*
(2 log jedinice)
<table>
<thead>
<tr>
<th>Organism</th>
<th>Effect of Ozone Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aspergillus niger</em> (Black Mount)</td>
<td>Destroyed by 1.5 to 2 mg/l</td>
</tr>
<tr>
<td><em>Bacillus</em> Bacteria</td>
<td>Destroyed by 0.2 m/l within 30 seconds</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>99% destruction after 5-min at 0.12 mg/l in water</td>
</tr>
<tr>
<td><em>B. cereus</em> (spores)</td>
<td>99% destruction after 5-min at 2.3 mg/l in water</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>90% reduction at 0.10-PPM for 33 minutes</td>
</tr>
<tr>
<td>Bacteriophage f2</td>
<td>99.99% destruction at 0.41 mg/l for 10-seconds in water</td>
</tr>
<tr>
<td><em>Botrytis cinerea</em></td>
<td>3.8 mg/l for 2 minutes</td>
</tr>
<tr>
<td><em>Cladosporium</em></td>
<td>90% reduction at 0.10-PPM for 12.1 minutes</td>
</tr>
<tr>
<td><em>Clostridium</em> Bacteria</td>
<td>Ozone susceptible</td>
</tr>
</tbody>
</table>
### Disinfection Efficacy of Gaseous Ozone against Selected Microorganisms on a Wet Surface over 8 hours.

<table>
<thead>
<tr>
<th>Exposure Time (hours)</th>
<th>E. coli</th>
<th>Salmonella typhimurium</th>
<th>Listeria monocytogenes</th>
<th>Staphylococcus aureus</th>
<th>Streptococcus pyogenes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CFU/cm²</td>
<td>Log CFU/cm²</td>
<td>CFU/cm²</td>
<td>Log CFU/cm²</td>
<td>CFU/cm²</td>
</tr>
<tr>
<td>0</td>
<td>rep. 1</td>
<td>500,000,000</td>
<td>8.70</td>
<td>760,000,000</td>
<td>8.88</td>
</tr>
<tr>
<td></td>
<td>rep. 2</td>
<td>550,000,000</td>
<td>8.74</td>
<td>990,000,000</td>
<td>9.00</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>8.72</td>
<td>8.94</td>
<td>8.22</td>
<td>8.84</td>
</tr>
<tr>
<td>8</td>
<td>rep. 1</td>
<td>&lt;1</td>
<td>&lt;0.00</td>
<td>&lt;1</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td></td>
<td>rep. 2</td>
<td>&lt;1</td>
<td>&lt;0.00</td>
<td>&lt;1</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>&lt;0.00</td>
<td>&lt;0.00</td>
<td>&lt;0.00</td>
<td>&lt;0.00</td>
</tr>
<tr>
<td>Reduction</td>
<td>Mean</td>
<td>&gt;8.72</td>
<td>&gt;8.94</td>
<td>&gt;8.22</td>
<td>&gt;8.84</td>
</tr>
</tbody>
</table>

**Notes:**
1) Reduction = (Mean Log₁₀ count of untreated “0” min. samples) - (Mean Log₁₀ count of subject time variable).
2) % Reduction based upon mean Log₁₀ reduction.
3) Ozone levels for the 8 hour treatment was ca. 158 ppm.
The test result for PIE Ozonation system for water disinfection
Ozone Solubility & Temperature

- Low Dissolved Ozone at High Temp (25+ °C)
- High Dissolved Ozone at Low Temp (5-20 °C)

Ozone Gas

H₂O
AOP (unapređeni proces dezinfekcije) jedna meksička bolnica
Right: control box for electrodes. Left: control of pH and redox

3 copper/silver electrodes

Ionization (disinfection) with 2 copper/silver electrodes.
Biological fouling of RO membranes

A = scanning electron microscope (SEM) image of bacterial micro-colonies formed on the surface of a cellulose acetate RO membrane after approximately 3 days of operation on pretreated municipal wastewater;

B = a biologically fouled spiral-wound RO membrane element;

C = transmission electron micrograph (TEM) of rod-shaped bacteria attached to an RO membrane surface;

D = TEM of a mature membrane biofilm;

E = nascent biofilm on permeate surface of a CA membrane
primena nanomaterijala u dezinfekciji
Anti Virus = Auto Disinfection

Pathogens (virus, bacteria) reduced to 0.1% on Silver based antimicrobial surface

“[mask] mask disinfects itself during and in between uses.”
Figure 1 Conceptualization of biofilm development and dynamic behaviors


Stickler DJ (2008) Bacterial biofilms in patients with indwelling urinary catheters
Nat Clin Pract Urol doi:10.1038/ncpuro1231
Figure 9 Examples of mucoid, noncrystalline biofilms formed on all-silicone catheters after 4 days of incubation in a laboratory model of the bladder.

Ozone Biocidal Behavior

Before ozone treatment

After ozone treatment

1. Ozone oxidizes cell membrane, causing osmotic bursting
2. Ozone continues to oxidize enzymes and DNA

Air Liquide Americas Corp., Chicago Research Center; James T.C. Yuan, Ph.D., year 2000
ZAHVALIJEM NA PAŽNJI !