Evaluation of Different Silver Compounds Applied to Point-of-Use Ceramic Water Filters

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Outline

• Disinfectant properties of different silver compounds
• Materials and methods
• Results
  – Sorption/desorption test
  – Disinfection performance of colloidal silver (nAg)
• Conclusion
• Future Experiments
Why silver?

• The antibacterial properties of silver have been used for centuries
• Several mechanisms of bacteria inactivation
• Recent advances in nanotechnology make the production of silver nanoparticles very easy
Antimicrobial properties of AgNPs

Silver nanoparticles

• Silver as alternative to chlorine
• Disinfectant properties of silver can be used to add biocide properties to different materials and/or prevent biofilm growth
• Currently more than 240 products contain silver nanoparticles

Silver Implication

- Silver ions non-toxic to humans, but can produce Argyria
- Silver nanoparticles have proved to be toxic to aquatic organisms*
- Consumption of high concentrations of silver nanoparticles (1 gr/day) has been reported to be harmful for humans**

** Archer SL. 2008. Dilated cardiomyopathy and left bundle branch block associated with ingestion of colloidal gold and silver is reversed by British antiLewisite and vitamin E: the potential toxicity of metals used as health supplements. Canadian Journal of Cardiology. 24(5),397-399.
Silver in ceramic filters

• Silver nanoparticles (colloidal silver)
  – Colargol: Argenol laboratories
    • Chemical reduction
    • 70-77% Ag w/w
    • average size 45 nm (hydrodynamic diameter)
    • Stabilized by proteins

• Silver nitrate
  • Purity 99.8%
  • 63% Ag w/w
Silver in ceramic filters

• Post firing
  – Painting (Ag-NPs and AgNO₃): 32-96 mg/filter
    • 33% of CWF factories
  – Dipping: uptake of silver depends on concentration of solution and porosity (recommend 800 mg/L)
    • 56% of CWF factories

• Pre-fired
  – Dry mix: proprietary information
    • 11% of CWF factories
Research objectives

• Evaluate silver uptake on different ceramic filters
  – Differences between Ag-NPs and AgNO$_3$
  – Determine optimum concentration
• Evaluate the effect of different ceramic materials on silver uptake
  – Determine if different mineralogy and porosity affect the uptake
• Determine desorption of silver compounds
  – Evaluate the effect of water chemistry
• Evaluate the disinfection performance of colloidal silver
  – Evaluate the effect of water chemistry
Materials and Methods
Materials

• Six samples of ceramic filters without silver
  – USA (A)
  – Guatemala (B)
  – Ghana (C)
  – Peru (D)
  – Nicaragua (E)
Methods

• Characterization of materials

• Ceramics
  • Porosity: water intrusion
  • Composition: SEM/EDS

• Silver compounds
  • Silver nitrate:
    — Concentration: ion selective probe
  • Colloidal silver:
    — Concentration: ICP-MS, spectrophotometer
    — Size: DLS, TEM, EDS
Methods

**Sorption Isotherms**
- 0.5 grams of ceramic
- 24 hours
- 25 °C
- Protected from light

**Batch desorption tests**
- Two steps
- 24 hours
- 25 °C
- Protected from light
Results

Sorption and Desorption of Different Silver Compounds
Characterization: Ceramics

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>Average Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA (A)</td>
<td>40.29% ± 0.40%</td>
</tr>
<tr>
<td>Guatemala (B)</td>
<td>45.40% ± 0.85%</td>
</tr>
<tr>
<td>Ghana (C)</td>
<td>47.87% ± 2.07%</td>
</tr>
<tr>
<td>Peru (D)</td>
<td>43.87% ± 3.58%</td>
</tr>
<tr>
<td>Nicaragua (E)</td>
<td>45.20% ± 3.96%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>14.06</td>
<td>20.04</td>
<td>16.95</td>
<td>21.54</td>
<td>13.54</td>
</tr>
<tr>
<td>Si</td>
<td>43.91</td>
<td>26.25</td>
<td>50.17</td>
<td>37.2</td>
<td>38.55</td>
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<tr>
<td>Ca</td>
<td>15.24</td>
<td>18.79</td>
<td>2.56</td>
<td>0.63</td>
<td>4.5</td>
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<tr>
<td>K</td>
<td>6.72</td>
<td>3.68</td>
<td>2.79</td>
<td>3.09</td>
<td>1.69</td>
</tr>
<tr>
<td>Mg</td>
<td>3.86</td>
<td>4.86</td>
<td>1</td>
<td>0.73</td>
<td>1.34</td>
</tr>
<tr>
<td>Na</td>
<td>4.84</td>
<td>0.22</td>
<td>0.15</td>
<td>29.75</td>
<td>24.53</td>
</tr>
<tr>
<td>O</td>
<td>2.32</td>
<td>2.09</td>
<td>2.94</td>
<td>0.79</td>
<td>0.62</td>
</tr>
<tr>
<td>Ti</td>
<td>2.32</td>
<td>2.09</td>
<td>2.94</td>
<td>0.79</td>
<td>0.62</td>
</tr>
<tr>
<td>Ag</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
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</table>

**Total**
Characterization: Colloidal Silver
Sorption: Colloidal Silver

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>$\frac{1}{n}$</th>
<th>$k$</th>
<th>$R^2$</th>
<th>$\frac{1}{n}$</th>
<th>$k$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.94</td>
<td>0.027</td>
<td>0.999</td>
<td>0.56</td>
<td>0.039</td>
<td>0.479</td>
</tr>
<tr>
<td>B</td>
<td>0.65</td>
<td>0.305</td>
<td>0.965</td>
<td>0.47</td>
<td>0.313</td>
<td>0.788</td>
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<tr>
<td>C</td>
<td>0.99</td>
<td>0.019</td>
<td>0.985</td>
<td>1.03</td>
<td>0.001</td>
<td>0.866</td>
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<tr>
<td>D</td>
<td>0.74</td>
<td>0.135</td>
<td>0.955</td>
<td>0.51</td>
<td>0.170</td>
<td>0.834</td>
</tr>
<tr>
<td>E</td>
<td>0.97</td>
<td>0.027</td>
<td>0.986</td>
<td>0.86</td>
<td>0.005</td>
<td>0.982</td>
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</tbody>
</table>
Sorption: Silver Nitrate

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>1/n</th>
<th>KNO₃</th>
<th>R²</th>
<th>1/n</th>
<th>Ca(NO₃)₂</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.75</td>
<td>0.0341</td>
<td>0.999</td>
<td>1.27</td>
<td>0.001</td>
<td>0.479</td>
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<tr>
<td>B</td>
<td>0.38</td>
<td>2.4158</td>
<td>0.965</td>
<td>0.51</td>
<td>1.131</td>
<td>0.788</td>
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<tr>
<td>C</td>
<td>1.09</td>
<td>0.0038</td>
<td>0.985</td>
<td>1.25</td>
<td>0.001</td>
<td>0.866</td>
</tr>
<tr>
<td>D</td>
<td>0.59</td>
<td>0.2275</td>
<td>0.955</td>
<td>0.93</td>
<td>0.031</td>
<td>0.834</td>
</tr>
<tr>
<td>E</td>
<td>1.25</td>
<td>0.0003</td>
<td>0.986</td>
<td>1.16</td>
<td>0.003</td>
<td>0.982</td>
</tr>
</tbody>
</table>
Desorption: Colloidal Silver

USA (A), Guatemala (B), Ghana (C), Peru (D), Tanzania (E), and Nicaragua (F)
Desorption: Silver Nitrate

USA (A), Guatemala (B), Ghana (C), Peru (D), Tanzania (E), and Nicaragua (F)
Results

Disinfection Performance of Colloidal Silver at Different Water Composition
Respiration tests
Effect of different ions dissolved in water on the size of colloidal silver
Charge of the colloidal silver particles at different water composition
Silver ions release from colloidal silver particles at different water conditions
Antibacterial properties of colloidal silver particles at different water compositions
Conclusions
Conclusions

• Different ceramic materials have different uptakes.
• Bigger uptake differences with AgNO₃ than AgNPs
• Higher silver uptake with AgNPs
• Monovalent ions dissolved in water seem to have little or no effect on silver sorption
• Silver nitrate desorption is about 1 log higher than silver nanoparticles desorption
• Dissolved ions can reduce the effectiveness of colloidal silver
Future experiments

• Full disks experiments
  – Effect of local materials
  – Effect of type and concentration of silver compounds
  – Evaluate biofilm formation on porous matrix
Thanks

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