Impact of Silver Nanoparticle Concentration and Size in Colloidal-Silver-Impregnated Ceramic Filters for Point-of-Use Removal of E. coli and MS-2 Phage

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Presentation Outline

• Problem definition
• Point-of-use water treatment
• Laboratory performance of ceramic water filters – Silver effects
• Acknowledgement: NSF
Problem Definition

• 1.1 billion people without access to an improved water supply
• 2.5 billion without access to an improved sanitation system
• 2 million child deaths per year
Water Quality Parameters

- Turbidity
- Waterborne pathogens
  - Viruses
  - Bacteria (*V. cholerae*, pathogenic *E. coli*, etc.)
  - Protozoa (*Cryptosporidium*, *Giardia*, etc.)
Point-Of-Use Water Treatment

- Household level
- Effective technological performance
- Simple to use
- Low cost (local materials and labor)
- Socially acceptable
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling</td>
<td>Sterilizes water</td>
<td>Energy, cultural acceptability, no turbidity removal, cool-down period, recontamination</td>
</tr>
<tr>
<td>Safe Water System</td>
<td>Effective disinfectant, low cost; local labor, simple to use</td>
<td>Taste; no turbidity removal, short shelf life</td>
</tr>
<tr>
<td>Solar Disinfection</td>
<td>Deactivates pathogens, cheap; no fuel needed, easy to use</td>
<td>Long treatment time, no turbidity removal, cool-down period, may not be culturally acceptable</td>
</tr>
<tr>
<td>Natural coagulants</td>
<td>Turbidity removal, locally produced, cheap, often culturally acceptable</td>
<td>May not remove all pathogens, not well studied in community settings</td>
</tr>
<tr>
<td>PuR sachets</td>
<td>Eliminates bacteria and turbidity, effective disinfectant</td>
<td>Taste, not locally produced, “one-size-fits-all” design</td>
</tr>
<tr>
<td>Ceramic filters</td>
<td>Microorganism and turbidity removal, local materials and labor, culturally acceptable</td>
<td>Fragile, significant infrastructure at start-up</td>
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Silver nanoparticles

- Also called “colloidal silver”
- Aqueous suspension of zero-valent silver particles
- Aqueous phase reduction of silver nitrate by citrate
- Highly effective bacterial disinfectant
Questions...

• Do silver nanoparticles improve filter performance?
• Does the nanoparticle loading affect performance?
• Does nanoparticle size affect performance?
• Bacteria versus virus?
Distribution of Commercial Products by Nanomaterial Type/Form

- Coating: 7 General Commercial Products, 1 Precursor Products
- Coating/Spray: 10 General Commercial Products, 0 Precursor Products
- Powder: 3 General Commercial Products, 4 Precursor Products
- Solid: 36 General Commercial Products, 5 Precursor Products
- Liquid: 50 General Commercial Products, 6 Precursor Products
- Spun: 13 General Commercial Products, 3 Precursor Products
- N/A: 43 General Commercial Products, 1 Precursor Products
Silver Nanoparticle Characterization

Size Distribution by Volume

- Record 1: 10mg/mL Jim Smith AgNP 0mM ions 1
- Record 2: 10mg/mL Jim Smith AgNP 0mM ions 2
- Record 3: 10mg/mL Jim Smith AgNP 0mM ions 3
- Record 4: 10mg/mL Jim Smith AgNP 0mM ions 4
- Record 5: 10mg/mL Jim Smith AgNP 0mM ions 5

Image of TEM analysis showing particles sized 30nm.
Nanoparticle Characterization

Ag-NP characterization for Argenol and fabricated particles using transmission electron microscopy (TEM), dynamic light scattering (DLS) and UV-Vis spectrometry

<table>
<thead>
<tr>
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<th>TEM (nm)</th>
<th>DLS (nm)</th>
<th>UV-Vis Peak (nm)</th>
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</thead>
<tbody>
<tr>
<td>Argenol</td>
<td>14.6</td>
<td>28.0</td>
<td>386</td>
</tr>
<tr>
<td>1:1 Fabricated</td>
<td>18.1</td>
<td>22.2</td>
<td>391</td>
</tr>
<tr>
<td>1:100 Fabricated</td>
<td>20.6</td>
<td>30.6</td>
<td>394</td>
</tr>
<tr>
<td>1:500 Fabricated</td>
<td>58.8</td>
<td>81.4</td>
<td>401</td>
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Laboratory Studies

- Filter disks for 1-D analyses
- Clay, flour, grog, and water
- With and without silver nanoparticles
- Test microbe: Escherichia coli and MS-2 Phage
Microbial Transport Experiments

- Hydraulic conductivity
- $[^3\text{H}]\text{H}_2\text{O}$ transport
- Microbe transport (pulse injection)
- Tracer and microbial transport simulations
- Silver release from filters
Experimental apparatus
Percent *E. coli* removal = 97.9%
Percent *E. coli* removal = 98.6%
Percent *E. coli* removal = 99.9%
Effect of Ag-NP concentration on *E. coli* transport
Effect of Ag-NP concentration on virus transport
Effect of Ag-NP size on *E. coli* transport
Effect of Ag-NP size on virus transport
Virus disinfection in batch reactors with silver nanoparticles
E. coli effectively removed/deactivated

MS2 virus removal not as effective

Silver nanoparticles contribute to treatment of E. coli, but effects on virus are small

For E. coli, removal improves with increasing Ag-NP concentration and decreasing particle size

Ag-NP size and concentration have little effect on virus removal
Questions?