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**Research on Nano-Deposited Ceramic Materials to  
Provide Clean Water for Developing Countries\***



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# The World Water Crisis



- Because of the lack of sanitary systems, diseases such as typhoid, cholera, dysentery, and gastro-enteritis are on the rise
- Millions of women and children spend several hours a day collecting water from distant, often polluted sources, resulting in no time for education or improvement in quality of life
- Every year, 3.5 million people die from water-related disease, and this includes 4,200 children every day.
- A third of the people without access to an improved water source live on less than \$1 a day and two thirds of the people live on less than \$2 a day. Despite this they often pay 5-10 times more per liter of water
- Point-of-use water filters have been developed as a temporary solution for the many problems related with unsafe water
- Water projects in developing countries fail at an average of 50% or higher.



# Research Objectives

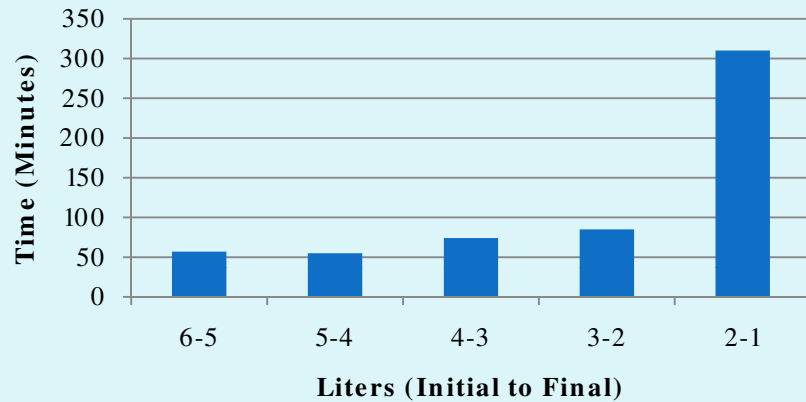


- Testing effectiveness of Ceramic Filters for eliminating pathogenic microorganisms typified by E. coli bacteria
- Investigating the biocidal activity of silver nano-particles coating
- Determining filter flow-rates with and without silver nano-particle coating
- Examining the mechanical robustness and durability of filters
- Investigating the microbial population present in new and used filters
- Studying the effect of cleaning methods on effectiveness of filters.

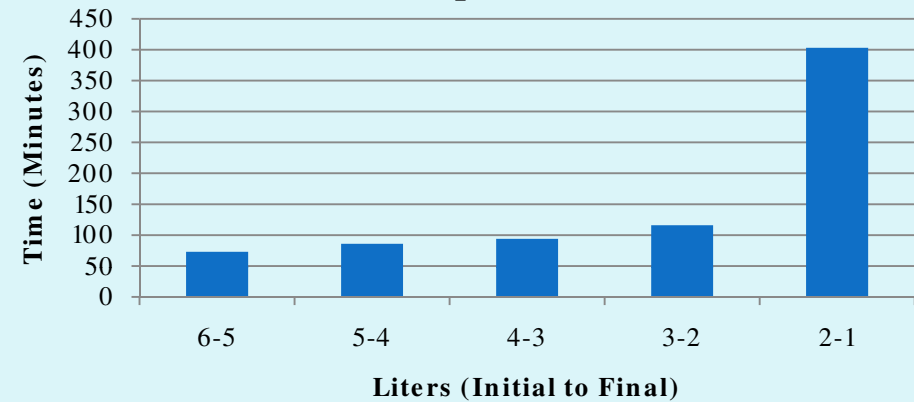
# Flow Rates Before and After Applying Silver Nano-Particle Coating



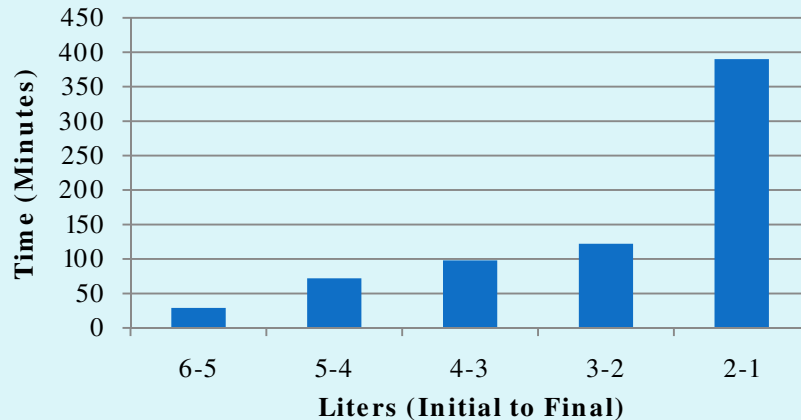
**a) Before Silver Application**



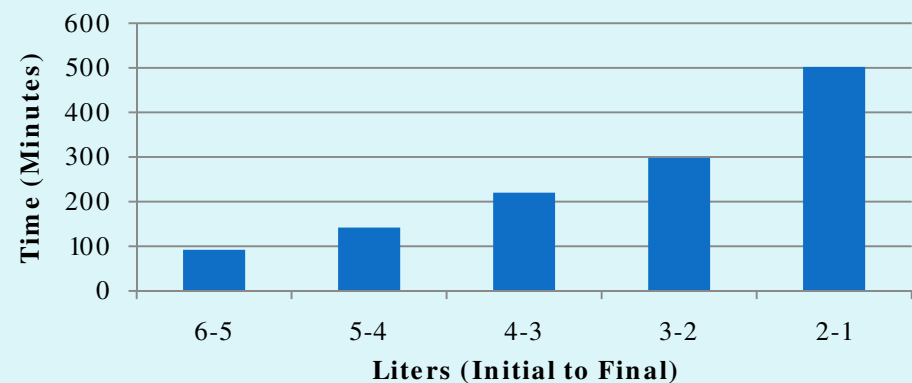
**a) Before Development of Biofilm**



**b) After Use and Silver Application**



**B) After Use and Development of Biofilm**



- The study indicates that silver nano-coating has little effect on the flow rate.
- Development of biofilm in the absence of silver nano-coating can reduce the flow rate significantly.

# Effectiveness of Filters Without Silver Nano-Particles Coating



Old Filter with Cracks Sealed with Epoxy Resin				New Filter Without Any Visible Cracks			
Pre-Filtration	Colonies	Post-Filtration	Colonies	Pre-Filtration	Colonies	Post-Filtration	Colonies
1:10	TMTC *	1:10	TMTC *	1:10	TMTC *	1:10	147
1:10 <sup>3</sup>	TMTC *	1:10 <sup>2</sup>	TMTC *	1:10 <sup>3</sup>	TMTC *	1:10 <sup>3</sup>	15
1:10 <sup>5</sup>	TMTC *	1:10 <sup>3</sup>	TMTC *	1:10 <sup>5</sup>	TMTC *	1:10 <sup>4</sup>	0
1:10 <sup>6</sup>	282	1:10 <sup>4</sup>	TMTC *	1:10 <sup>7</sup>	20	1:10 <sup>5</sup>	0
1:10 <sup>7</sup>	27	1:10 <sup>5</sup>	TMTC *	1:10 <sup>8</sup>	7	1:10 <sup>6</sup>	0
		1:10 <sup>6</sup>	208	1:10 <sup>9</sup>	2	1:10 <sup>7</sup>	0

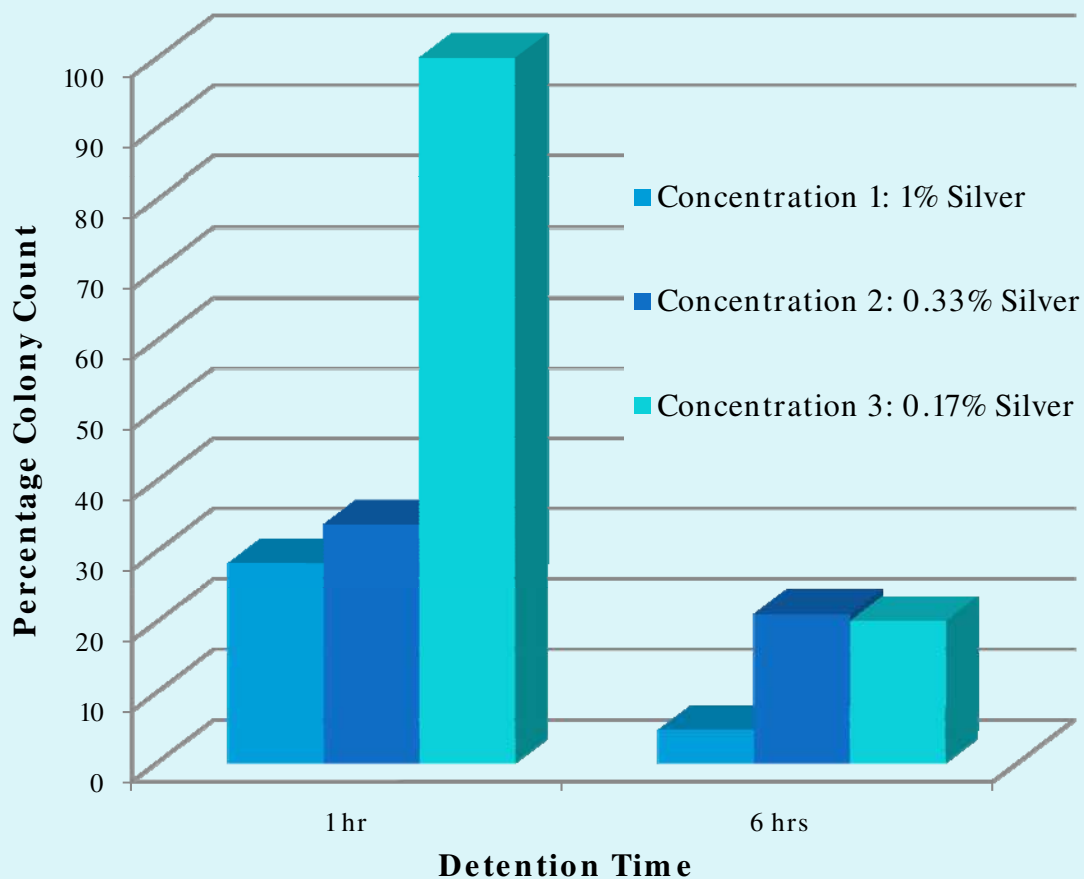
- For each test,  $2 \times 10^9$  cells of *E. Coli* were inoculated into 6 L of sterile Echo Park pond water, allowed the water to filter, and then took samples of the filtrate for coliform testing. The testing technique employed serial dilutions followed by membrane filtration and plate growth. The resulting colonies were then counted by established procedures.
  - Earlier tests showed no reduction in bacteria, leading to the conclusion that the filters were cracked. The cracks were sealed with Epoxy resin, but it resulted in only 30% reduction in *E. Coli* colony counts.
  - A new filter without any visible cracks exhibited a 99% reduction in *E. Coli* colony counts.

\*TMTC- Too Many to Count

# Silver Nano-Particle Biocidal Activity Tests



**Biocidal Effect Observed at Different Silver Concentrations and Detention Times**



- In order to test the biocidal effectiveness of silver nanoparticles solution, varying concentrations of silver solution were employed at two different detention times to optimize silver concentration.
- Results showed that the lowest colony counts were observed at 1% silver concentration and a 6-hour detention time.

# Effectiveness of Filters with Colloidal Silver Coating

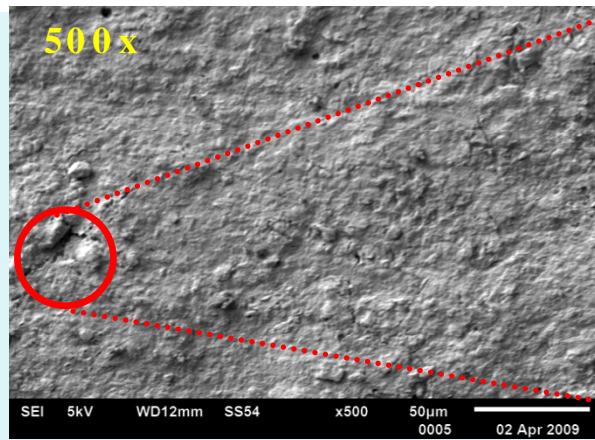


Filter with Colloidal Silver Nano- Coating			
Pre-Filtration	Colonies	Post-Filtration	Colonies
1:10	TMTC *	1:10	0
1:10 <sup>3</sup>	TMTC *	1:10 <sup>3</sup>	0
1:10 <sup>5</sup>	5	1:10 <sup>4</sup>	0
1:10 <sup>7</sup>	2	1:10 <sup>5</sup>	0
1:10 <sup>8</sup>	0	1:10 <sup>6</sup>	0
1:10 <sup>9</sup>	0	1:10 <sup>7</sup>	0

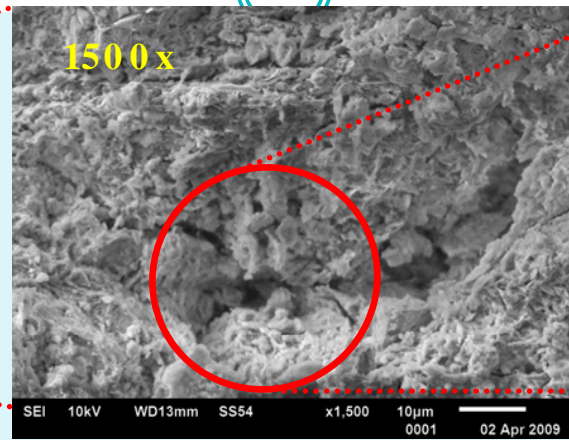
Filter with Colloidal Silver Nano-Coating, After Scrubbing			
Pre-Filtration	Colonies	Post-Filtration	Colonies
1:10	TMTC *	1:10	0
1:10 <sup>3</sup>	TMTC *	1:10 <sup>2</sup>	0
1:10 <sup>5</sup>	327	1:10 <sup>3</sup>	0
1:10 <sup>7</sup>	1	1:10 <sup>4</sup>	0
1:10 <sup>8</sup>	0	1:10 <sup>5</sup>	0

- Based on the preliminary data from the biocidal effect of silver, a 0.67 % solution of colloidal silver was employed for coating the inside and outside of the filters
- Results showed that silver nano-particle coating was highly effective in deactivating E. Coli bacteria.
- Vigorous scrubbing of filters did not erode the colloidal silver nano-coating significantly.

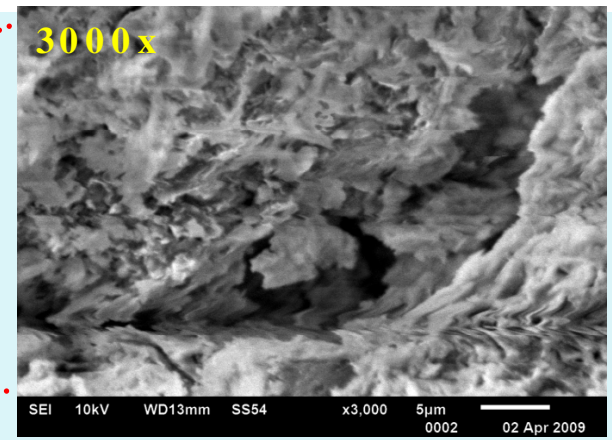
# Scanning Electron Microscopy Images and Energy-Dispersive X-Ray Analysis of Ceramic Filter Surfaces



(a) SEM Image of the Ceramic Filter Surface with a Nano-Deposition Coating of Colloidal Silver (x 500)

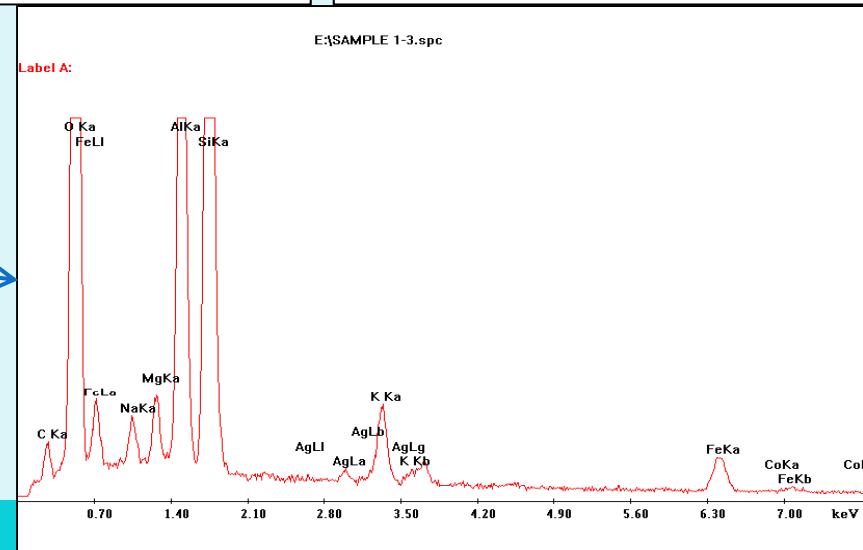


(b) SEM Image of the Ceramic Filter Surface with a Nano-Deposition Coating of Colloidal Silver (x 1500)



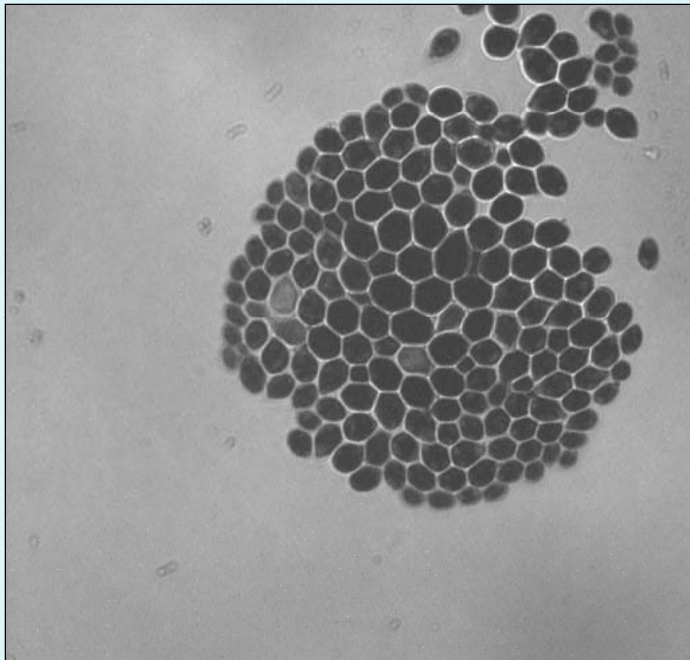
(c) SEM Image of the Ceramic Filter Surface with a Nano-Deposition Coating of Colloidal Silver (x 3000)

(d) Energy Dispersive X-Ray Analysis Spectra Showing the Elemental Analysis of the Ceramic Filter with Nano-Deposition of Colloidal Silver Particles



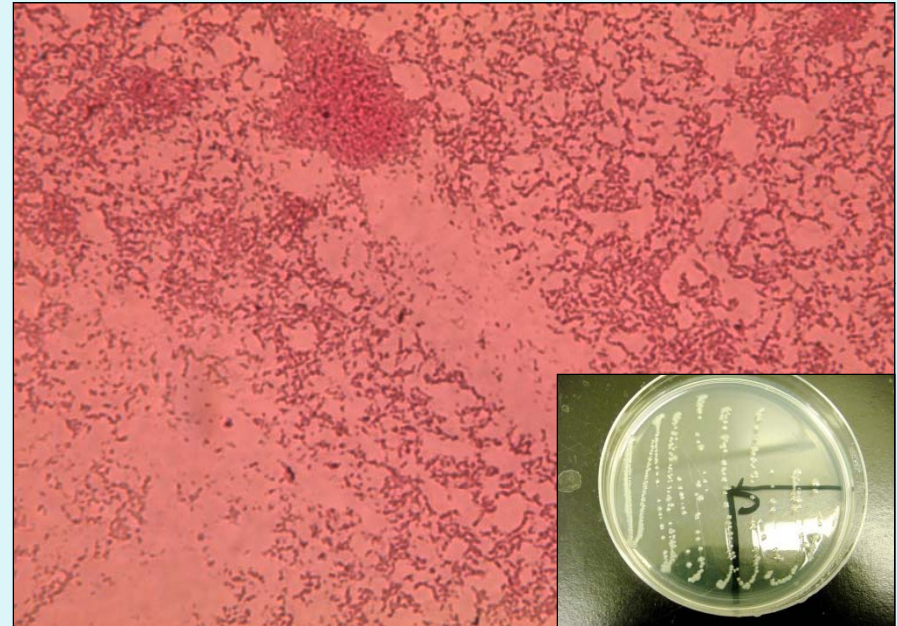


# Confocal and Light Microscopy Images of Microorganisms Obtained from the Ceramic Filters



(a) Confocal microscopy image of unknown microorganism growth on the surface of new and used filters (x 1000)

This Gram-positive microorganism was speculated to be a fungal species.



(b) Light microscopy image of *E. coli* bacteria in surface water before filtration (x 400). The *E. coli* are represented by Gram- negative rods.

**Inset:** *E. coli* colonies grown on a typical streak plate

# Researchers at Work at Various Stages of the Project





# Conclusions



- High concentrations of silver nano-particles applied on new filters were effective in removing E. Coli.
- Filters were highly susceptible to fractures and cracks leading to significant breakthrough of bacteria even after mild usage.
- Under laboratory conditions, the filters appeared to harbor microbial populations even after intense scrubbing and bleaching.
- Fragility of the filters and their tendency to develop cracks, fractures and fissures were points of major concern.
- Filters appear inadequate as point-of-use household water- filtration systems, especially in rural areas.

# Recommendations



- The structural quality of ceramic filters is inadequate for efficient removal of microorganisms from surface and ground water supplies. The filters have a high tendency to break and cannot be reconditioned or repaired.
- Ceramic filters may require expensive colloidal silver nanoparticle coatings. Furthermore, these filters maintain very low flow rates.
- Under the circumstances, we recommend the use of bio-sand filters as a more efficient and cost-effective point-of-use device.