Evaluating the Impact of Production Variables on the Effluent Water Quality of Ceramic Pot Filters

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Kristen Jellison, Julie Napotnik, Natalie Smith, Kyle Doup (Lehigh University)
Justine Rayner, Jesse Schubert (PATH)
Vinka Oyanedel-Craver (University of Rhode Island)
Daniele Lantagne (CDC, Harvard University)

Outline

- Motivation
- Project 1: Full-scale filter study
- Project 2: Ceramic disk study
- Significance of Results

Motivation

Challenge: Maintaining filter manufacturing and quality control standards in decentralized production facilities

Mix clay and burn-out material

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Mold into filter shape and dry

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Fire filter to ~900 °C

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Measure flow rate for quality control

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Add silver as bacteriocide

www.safewatertoday.org

Motivation

Production variables which may impact filter efficacy:

1. Silver
   - Type:
     - colloidal silver
     - silver nitrate
   - Application:
     - After firing: brushed on or dipped
     - Fired in: mixed into clay/burnable mix prior to firing
   - Quantity:
     - Concentration of silver solution
     - Mass of silver applied to filter

Motivation

Production variables which may impact filter efficacy:

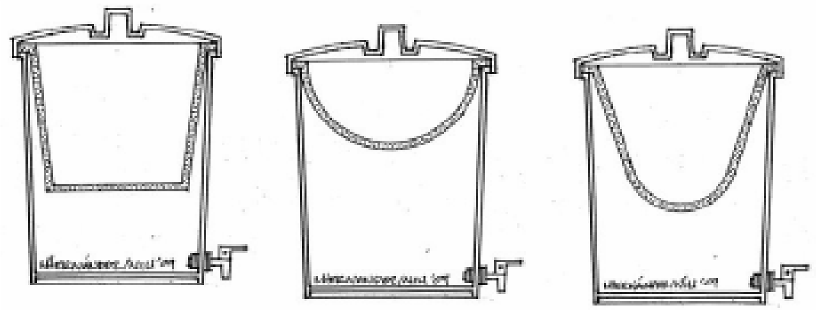
http://www.micro.iastate.edu/ugrad/bacteria-in-pore.html

2. Pore size and porosity
   – Affected by type, size, and amount of burn-out material added to clay
     • Types: sawdust, rice husks, peanut shells
     • Sieved size
     • Ratio of burn-out:clay
     • Mixing times of clay with burn-out
   – Affected by clay content
   – Affected by firing conditions

Motivation

Production variables which may impact filter efficacy:

3. Hydraulic properties
   – Amount of time it takes for water to pass through walls of filter
4. Filter shape
   – Original flat bottom (PFP)
   – Parabolic semi-spherical (Thirst-Aid)
   – Oblong, round bottom (FilterPure)



Potters for Peace (7-11 liters) | Thirst-Aid (10 liters) | FilterPure (6 liters)

(Hernandez 2009)

   – Wall thickness (1-3 cm)

Motivation

Production variables which may impact filter efficacy:

www.safewatertoday.org

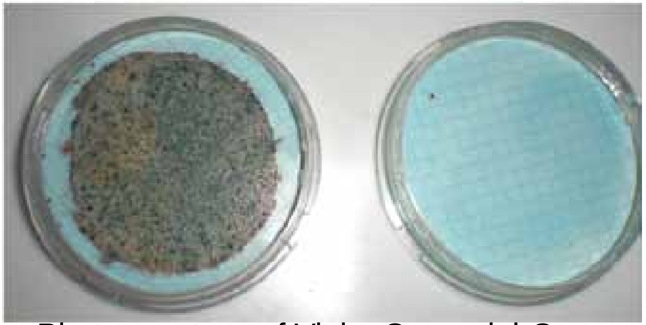


Photo courtesy of Vinka Oyanedel-Craver

5. Drying Time
6. Firing
   - Time (6-14 hrs firing, 12-24 hrs cooling)
   - Temperature (700-980 °C)
   - Rate that temperature is raised
   - Atmosphere in kiln

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Effect of production variables on microbiological removal in locally-produced ceramic filters for household water treatment

Daniele Lantagne[a]*, Molly Klarman[b], Ally Mayer[c], Kelsey Preston[c], Julie Napotnik[c] and Kristen Jellison[c]

[a]*Enteric Diseases Epidemiology Branch, Centers for Disease Control and Prevention, Atlanta, Georgia, USA;* [b]*Rollins School of Public Health, Emory University, Atlanta, Georgia, USA;* [c]*Department of Civil and Environmental Engineering, Lehigh University, Bethlehem, Pennsylvania, USA*

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Project 1

FULL-SCALE FILTER STUDY

Research Question

Is filter effectiveness impacted by:

– the method of silver application?

– the shape of the filter?

Filter effectiveness evaluated in terms of:

- Flow rate
- Turbidity reduction
- Log_{10} *E. coli* removal

Research Approach

PFP
- Flat bottom
- Colloidal silver painted on after firing
- Nicaragua

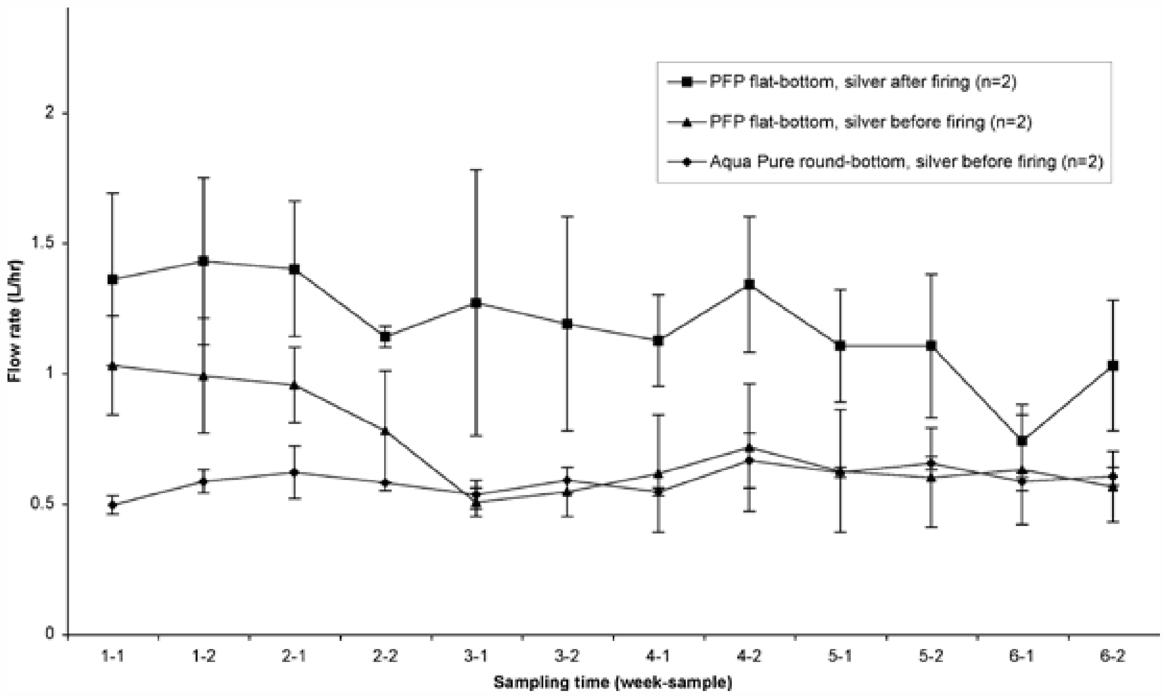
Modified PFP
- Flat bottom
- Fired-in colloidal silver
- Nicaragua

AquaPure
- Round bottom
- Fired-in colloidal silver
- Dominican Republic

Research Approach

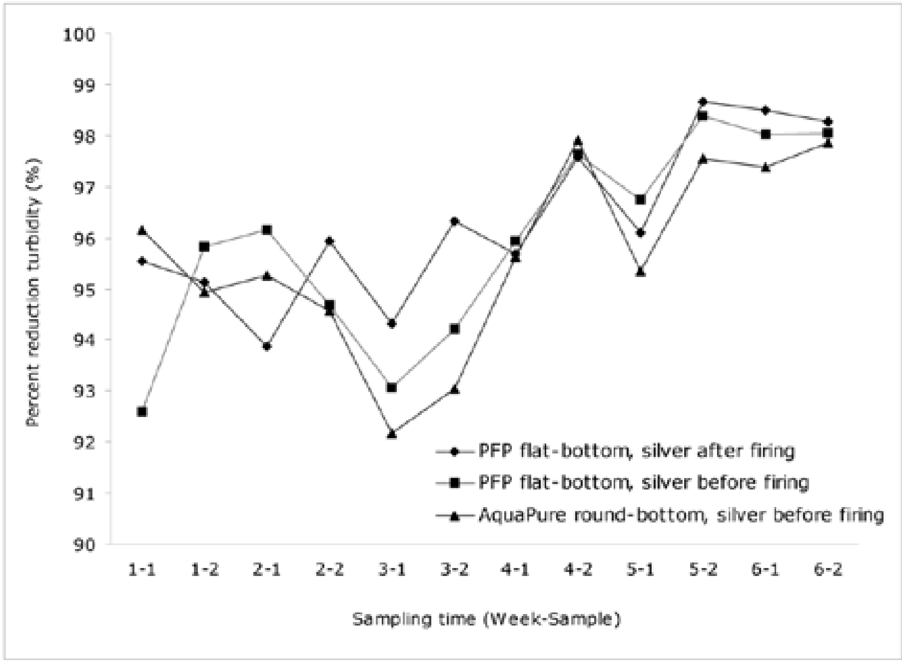
- Six-week study (six weeks of simulated normal use)
- 8 L/d added to each of 6 filters
  - Challenge water from Saucon Creek (Bethlehem, PA)
  - Turbidity adjusted to 30 ntu
- Water quality testing 2x/week for each filter
  - Turbidity reduction
  - *E. coli* removal (target spike = 1.25×10^6 CFU/L)
  - Flow rate

Results: Flow Rates



	Initial Flow (L/hr)	Flow at 6 weeks (L/hr)
PFP	1.03-1.69	0.78-1.28
Modified PFP	0.84-1.22	0.43-0.70
AquaPure	0.46-0.53	0.57-0.64

Results: Turbidity



Average Influent = 30.4 ntu (n=72, min=25.1, max = 35.8, SD = 2.3)

	Average Effluent (NTU)	
PFP	1.1	(n=24, min=0.3, max=2.0; SD=0.5)
Modified PFP	1.2	(n=24, min=0.3, max=2.5, SD=0.6)
AquaPure	1.3	(n=24, min=0.5, max=2.6, SD=0.6)

Results: *E. coli*

	$\log_{10}$ ***E. coli*** **reduction**
PFP	4.1 - 6.1
Modified PFP	3.1 - 6.0
AquaPure	3.6 - 6.0

Average Influent = 4.29×10^5 CFU/100 mL
(min=0, max = 1.3×10^6, SD = 3.89×10^5)

- All filter types effectively removed bacteria from challenge water
- All but 2 of 72 effluent water samples had no *E. coli* present in effluent
  - Both were effluent samples from Modified PFP filter
- No temporal evaluation or comparisons between filters because of variation in *E. coli* concentration in influent

Conclusion

- Method of silver application and shape did not impact filter effectiveness over 6-weeks of simulated normal use

- Further research needed to determine
  - Production variables associated with filter effectiveness
  - Standardized filter production procedures prior to scaling-up

Project 2

CERAMIC DISK STUDY

(In progress)

Project Goals

To define:

- the relationship between indicators of effectiveness (flow rate and/or porosity) and measured microbiological effectiveness
- the influence of production variables on porosity, flow rate and microbiological effectiveness
- which variables (and appropriate ranges) to control for in the manufacturing process

Overview of Research Plan

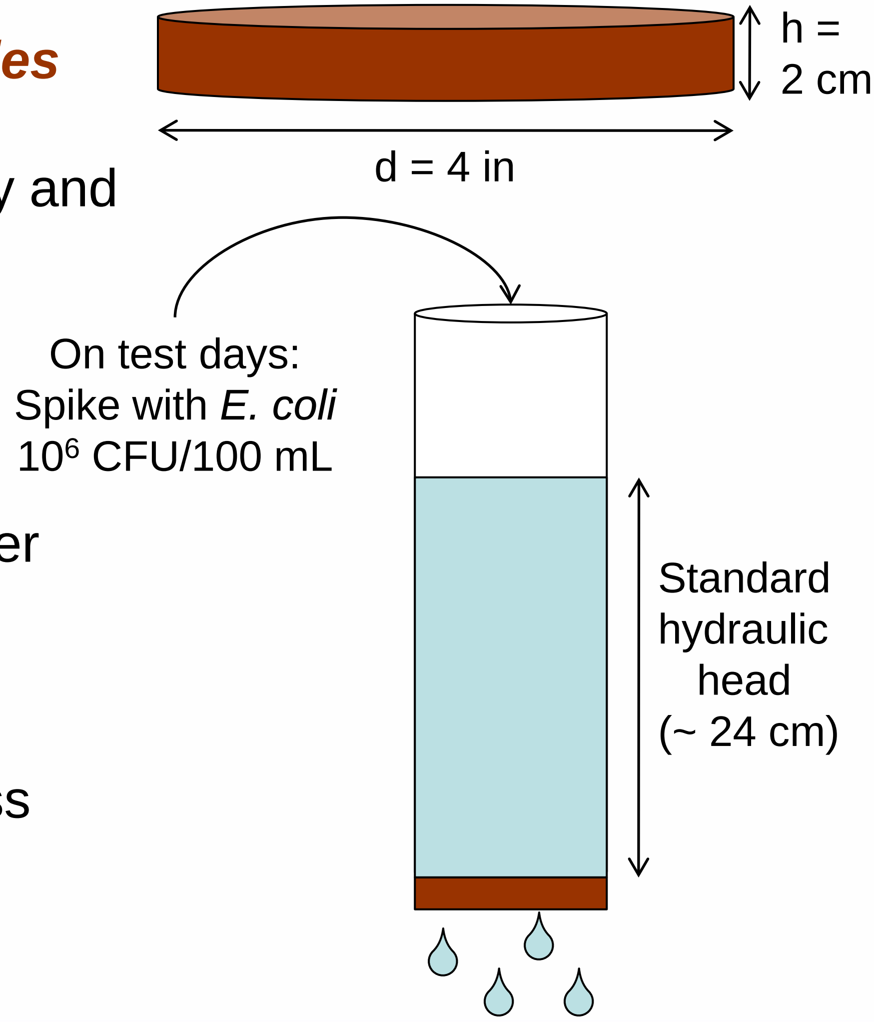
Manufacture ceramic disks

- ***various sets of production variables***
- production consistency confirmed through measurements of (i) porosity and (ii) flow rate

Test ceramic disks in triplicate

Testing for 4 weeks:

- Fill daily with dechlorinated water (saturated conditions)
- Tested 2x per week for
  - flow rate
  - microbiological effectiveness (*E. coli* removal)



Variables to be Tested

1. Ratio of clay:burn-out material
2. Burn-out sieve size
3. Burn-out particle size distribution
4. Burn-out type with different clay
5. Pressure applied during molding

www.pottersforpeace.org

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4 types of clay: Nicaragua, Indonesia, Tanzania, Cambodia

2 burn-out types: outer rice husk (RH), pine sawdust (SD)

Variables to be Tested

1. Ratio of clay:burn-out material

	Rice Husk (RH)	Sawdust (SD)
Clay #1	80:20 85:15 90:10	
Clay #2	80:20 85:15 90:10	
Clay #3		80:20 85:15 90:10
Clay #4		80:20 85:15 90:10

Variables to be Tested

2. Burn-out sieve size

	Rice Husk (RH)	Sawdust (SD)
Clay #1	<8/9 mesh (2.36 mm) <16 mesh (1.18 mm) <30 mesh (0.60 mm)	
Clay #2	<8/9 mesh (2.36 mm) <16 mesh (1.18 mm) <30 mesh (0.60 mm)	
Clay #3		<8/9 mesh (2.36 mm) <16 mesh (1.18 mm) <30 mesh (0.60 mm)
Clay #4		<8/9 mesh (2.36 mm) <16 mesh (1.18 mm) <30 mesh (0.60 mm)

Variables to be Tested

3. Burn-out particle size distribution

	Rice Husk (RH)	Sawdust (SD)
Clay #1	30-16 mesh (0.60-1.18 mm) 16-9 mesh (1.18-2.36 mm)	
Clay #2	30-16 mesh (0.60-1.18 mm) 16-9 mesh (1.18-2.36 mm)	
Clay #3		30-16 mesh (0.60-1.18 mm) 16-9 mesh (1.18-2.36 mm)
Clay #4		30-16 mesh (0.60-1.18 mm) 16-9 mesh (1.18-2.36 mm)

Variables to be Tested

4. Burn-out type with different clay

	Rice Husk (RH)	Sawdust (SD)
Clay #1		Prepare disks according to previous formula
Clay #2		Prepare disks according to previous formula
Clay #3	Prepare disks according to previous formula	
Clay #4	Prepare disks according to previous formula	

Variables to be Tested

5. Pressure (Prepare disks according to previous formula)

	Rice Husk (RH)	Sawdust (SD)
Clay #1	320 psi 660 psi 1000 psi	
Clay #2	320 psi 660 psi 1000 psi	
Clay #3		320 psi 660 psi 1000 psi
Clay #4		320 psi 660 psi 1000 psi

Additional Testing: Silver

Research Questions:

- Do local materials influence the amount of silver that incorporates into the CPF?
- Effect of water chemistry on sorption of silver to CPF?
- Effect of water chemistry on desorption of silver from CPF?
- Potential for internal biofilm formation in CPF impregnated with silver?

Testing with (i) colloidal silver and (ii) silver nitrate

Silver Testing: Phase I

What is the optimum concentration of silver to apply to the CPF?

- 3 concentrations of silver to be tested (duplicate filters per silver dose):
  - Colloidal silver: 0.032 mg/g, 0.5 mg/g, 5 mg/g
  - Silver nitrate: 0.032 mg/g, 5 mg/g, 50 mg/g
- Optimum concentration based on
  - Highest log removal of *E. coli*
  - Minimal silver desorption

Silver Testing: Phase I

Silver brushed on disks, disks dried

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Constant flow of sterile buffer solution through disks (0.6 mL/min)

↓

Measure initial release of silver from disk

↓

Measure log removal of *E. coli* for 10 days (influent: 10^6 CFU/100mL)

↓

Break disks ® submerge in solution with live/dead stain (detects any biofilm formation inside filter pores)

Silver Testing: Phase II

How does water chemistry influence disinfection performance of CPFs impregnated with silver?

- Use optimum silver dose (colloidal silver, silver nitrate) identified in Phase I
- 3 water chemistries tested (duplicate filters per water chemistry):
  - Monovalent salt
  - Divalent salt
  - High sulfate concentration
- Water chemistries used to:
  - Prepare silver solutions
  - As flow medium through disks

Silver Testing: Phase II

Silver (optimum concentration) brushed on disks, disks dried

↓

Constant flow through disks
(0.6 mL/min of the water chemistry to be tested)

↓

Measure initial release of silver from disk

↓

Measure log removal of *E. coli* for 10 days
(influent: 10^6 CFU/100mL)

↓

Break disks and submerge in solution with live/dead stain
(detects any biofilm formation inside filter pores)

Project Status

- Ceramic disks currently being manufactured
- Initial testing planned for late March 2011
- Lab testing completed by August 2011

- Next step – field testing at a factory to confirm the lab results are transferable for full-size filter production at factories

SIGNIFICANCE OF RESULTS

Anticipated Outcomes

- Identification of the variables (and their appropriate ranges) which should be controlled in the manufacturing process

- Ultimate goal: responsible scale-up of filter production worldwide
  - Standardized CPF production process to reduce variability in filter performance across different geographic locations

Questions?