Case Study of Microbial Growth in New Buildings with Water Conservation Features

Caroline Nguyen
Marc Edwards
Francis DiGiano
Carolyn Elfland

3rd International Conference on Sustainability Engineering and Science
Despite advances in water management and sanitation, waterborne disease outbreaks continue to occur in the United States. 

........* Legionella* accounted for 58% of outbreaks  93% of deaths
Energy Conservation

Water Conservation

Plumbing

Public Health

Co-authors Dr. Amy Pruden, William Rhoads, Kathita Chittaladakorn
General Characteristics of Premise Plumbing

- Long detention time
- Low disinfectant residuals
- Warmer temperatures
- Varied materials
- Large diurnal variation in flow

Changes in Regulation, Flow Patterns in Green Construction, and Improved Awareness of Waterborne Disease

Image: Randi Brazeau, Sheldon Masters
Highlights of:

• Unleaded Brass Performance Research
• Hex Chrome Cr(VI) Issue
• LEED (Building Water Quality)
• Legionella
• Changes in Water Chemistry
Highlights of:

- Unleaded Brass Performance Research
- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella
- Changes in Water Chemistry
Highlights of:

- Unleaded Brass Performance Research
- **Hex Chrome Cr(VI) Issue**
- LEED (Building Water Quality)
- Legionella
- Changes in Water Chemistry
Julia Roberts is Erin Brockovich

www.erinbrockovich.com
Why Cr(VI)?

Public Health Goal 0.02 ppb

<table>
<thead>
<tr>
<th></th>
<th>Current Standard [Cr(III)+Cr(VI)]</th>
<th>Proposed Standard [Cr(VI)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>US EPA</td>
<td>100 ppb</td>
<td>?</td>
</tr>
<tr>
<td>California</td>
<td>50 ppb</td>
<td>10 ppb</td>
</tr>
</tbody>
</table>

Suspected carcinogen in drinking water
## 20 Conditions (5 x 2 x 2)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Disinfectant (MRDL)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>316</td>
<td>Chlorine: 4 mg/L</td>
<td>6.5</td>
</tr>
<tr>
<td>316L</td>
<td>ClO$_2$: 0.8 mg/L</td>
<td>9.5</td>
</tr>
<tr>
<td>304</td>
<td>Cr(VI) Exceeded 10 ppb in just a few hours!</td>
<td></td>
</tr>
<tr>
<td>304L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2205</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Stainless Steel Sheet*
Mini Pipe Flow Systems

- **Metal**
- **Copper (Control)**
- **304 Stainless Steel**

**Disinfectant (MRDL)**
- None (Control)
- Chlorine 4 mg/L
- Chloramine 4 mg/L
- ClO₂ 0.8 mg/L

Diagram showing a pump connected to pipes, a hot plate, and a disinfectant feed.
Mini Pipe Flow System

Copper: 2", 9x

Stainless steel: (2" welded together), 9x

<table>
<thead>
<tr>
<th></th>
<th>Equivalence Pipe Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cu</strong></td>
<td>8.6”</td>
</tr>
<tr>
<td><strong>SS</strong></td>
<td>4.3”</td>
</tr>
</tbody>
</table>
Chlorine Dioxide

(or chlorine)
Copper Pipe with Chlorine Dioxide

Flow in

Flow out

\( \text{ClO}_2 \) Sample

Others

316 Stainless Steel (16% Cr)
Conclusion

• More than 10 ppb Cr(VI) can be formed after 8 hours exposure to stainless steel at 24.5°C in batch reactors (equivalent to 6.5 in pipe)

• Cr(VI) can be formed at concentrations up to 1000 ppb in small scale premise plumbing system at 60°C

• Even small amounts of stainless steel can be a source of significant Cr(VI)

• EPA point of compliance is proposed at treatment plant!
Highlights of:

• Unleaded Brass Performance Research
• Hex Chrome Cr(VI) Issue
• LEED (Building Water Quality)
• Legionella
• Changes in Water Chemistry
SURVEY OF GREEN BUILDING WATER QUALITY: IDENTIFYING PUBLIC HEALTH AND AESTHETIC CONCERNS

William Rhoads
Marc Edwards
What’s different about green water systems?

• **Water Age**: The amount of time that passes from the time the water enters a system to the time it is used
  – Does water have an expiration date?

• **On-site Treatment/New Sources of Potable Water**
Problems Associated with Water Age

- Taste and Odor
- Maintaining Chlorine Residuals
- Opportunistic Pathogen Growth/Legionella
- Copper and Lead Corrosion
How do green systems increase water age?

• Water Conservation
  – Campaigns
  – Metered and sensor faucets
  – Low-flow showerheads and taps
  – Dual flush, or compost toilets
  – Grey water reuse
  – Black water treatment and reuse

• Water Storage
  – Rainwater collection
  – Solar “pre-heat”

www.airdelights.com; Amazon.com; blog.oyster.com
www.buildingwithawareness.com;
http://reuseofwaterandrestrictions.weebly.com/gallery.html;
www.tamarac.org
Data: Brian Ramaley and Newport News, VA Waterworks
Simple Arithmetic

• Savings in each individual building

• Increased water age in distribution system
Even if a building makes no effort to save water, the water quality could still be affected by the cumulative savings of others buildings.
The Triple Conservation Condundrum

- Older water age coming into buildings
- Older water age within buildings
- Water storage with new water sources
Water Age – Low Flow

- UNC
  - Uses 3-5X less water

<table>
<thead>
<tr>
<th>Green Plumbing Devices?</th>
<th>Average potable water use (gal/ft²/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>63</td>
</tr>
<tr>
<td>Yes</td>
<td>26</td>
</tr>
<tr>
<td>No</td>
<td>10</td>
</tr>
<tr>
<td>Yes; non-potable for toilets</td>
<td>2</td>
</tr>
</tbody>
</table>
Legionella Proliferation in Green Devices?

- Lower flow
- Low pressure
- Pipe materials
- Temperature
- Magnetic mixing value

Sydnor et al. 2012
However, we found that nontouch electronic faucets were more likely to become contaminated with bacteria, including *L. pneumophila*, than manually operated faucets. We also found a trend toward continued higher rates of bacterial contamination of electronic faucets after chlorine dioxide remediation, suggesting that electronic faucets may be more difficult to disinfect with standard procedures. All electronic faucet internal components tested in this evaluation grew *L. pneumophila*, with some components showing continued growth of *L. pneumophila* after chlorine dioxide remediation.
Anonymous

- Net-zero energy
- Water Age – Storage
  - Solar pre-heat hot water system

400% increase in water age without “green” devices
Net Zero Energy/Net Zero Water

- Water Age – Rain Storage, Low flow fixtures, composting toilets
• 3,000 gal rainwater cistern
  – Automatically circulates water
  – GAC + UV treatment (+1 µm filter for potable water)

Very High Legionella Species Concentration
Conclusion...?

• Need better understanding of water age
  – Pipe sizing may need to be reduced to reduce storage times
  – Hot water system designs are problematic
Highlights of:

- Unleaded Brass Performance Research
- Hex Chrome Cr(VI) Issue
- LEED (Building Water Quality)
- Legionella (OPPPs)
- Changes in Water Chemistry
Project 4379:
Research Needs for Opportunistic Pathogens in Premise Plumbing: Experimental Methodology, Microbial Ecology and Epidemiology

Overview of Project, Drivers for Research and Outcomes

Marc Edwards, Amy Pruden (PI), Joe Falkingham
Opportunistic pathogens in premise plumbing are now the primary source of water-borne infectious disease in developed countries.

Per year: Up to 18,000 Legionnaire’s and 30,000 MAC cases

Not fecal-associated

Immunocompromised people particularly at risk

Regulatory challenge—who’s responsibility?

Opportunistic Pathogens

- L.pneumophila
- Mycobacterium avium complex (MAC)
- Acanthamoeba
- P. aeruginosa
- N. fowleri
## Pathogens of Concern

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Disease(s)</th>
<th>Host Organism Required?</th>
<th>Mode of Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Legionella pneumophila</em></td>
<td>Legionnaires’ disease or Pontiac fever in children</td>
<td>Yes</td>
<td>Inhalation or aspiration</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>Urinary tract infections, respiratory infections, dermatitis, soft tissue infections, bacteremia, bone and joint infections, GI infections</td>
<td>No</td>
<td>Wound infection; other modes of transmission are unknown</td>
</tr>
<tr>
<td><em>Mycobacterium avium</em></td>
<td>Pulmonary disease, cervical lymphadenitis (children)</td>
<td>No</td>
<td>Inhalation or aspiration</td>
</tr>
<tr>
<td>Acanthamoeba</td>
<td>Acanthamoeba keratitis</td>
<td>No</td>
<td>Wound infection</td>
</tr>
<tr>
<td><em>Naegleria fowleri</em></td>
<td>Primary amebic meningoencephalitis</td>
<td>No</td>
<td>Nasal aspiration</td>
</tr>
</tbody>
</table>
Opportunistic Premise Plumbing Pathogens

“OPPPPs” or “OPPPPPs”
Practical Drivers and Opportunities

- Increased reporting/detection
- Increased susceptible populations
- Main water distribution system upgrades
- Premise plumbing upgrades
- Green building/green devices
- Energy sustainability links

These are profoundly impacting waterborne disease ...
Why *Legionella*?

- Legionnaires’ disease (LD)
  - 8,000-18,000 people infected each year\(^1,3\)
  - 5-30% mortality rate\(^1\);
  - >40% mortality rate for immunocompromised\(^2\)

- Pontiac Fever
  - Infects 95% of people exposed\(^4\)

---

1. [http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5407a1.htm](http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5407a1.htm)
VA under scrutiny after Legionnaires' cases in Pittsburgh
By Nelli Black and Drew Griffin, CNN
updated 6:23 PM EST, Fri December 14, 2012

Electronic Faucets Unsafe for Use in High-Risk Patient Hospital Settings: Study Shows Automatic Faucets Carry High Levels of Bacteria
Author: SHEA
Date Published: 3/31/2011 9:00:00 AM
Publication Format: HTML, PDF
Abstract:

Dallas, TX (March 31, 2011) – Researchers at The Johns Hopkins University School of Medicine have determined that electronic faucets are more likely to become contaminated with unacceptably high levels of bacteria, including *Legionella* spp., compared with traditional manually operated faucets. The study will be presented on Saturday at the annual meeting of the Society for Healthcare Epidemiology of America (SHEA).
Microbial Ecology of Residential Hot Water Heater Systems:

Role of Hot Water System Type/Design on Factors Influential to Pathogen Re-growth: Temperature, Chlorine Residual, Hydrogen Evolution and Sediment

Randi Brazeau, Amy Pruden and Marc Edwards
October 4, 2013
Background

• Conventional Wisdom: Temperature is the Key
  – WHO vs. US temperature setting
  – 48 °C → typically closer to 42-45 °C

Pathogen Growth → Water Heater Type

  – Stratification in Electric Water Heaters vs. Gas
    (Lacroix, 1999)

  – Pinellas County and CDC: Legionella incidence higher in buildings with hot water recirculation (Moore, et al., 2006)
AOC (food) Generation Mechanisms

Four Potential Mechanisms

1. Nitrification (Zhang et al. 2009)
2. $\text{H}_2$ oxidation (Morton et al. 2005)
3. Sorption to Iron/Aluminum Sediments (Butterfield et al. 2002)
4. Organics leaching from pipe materials (PEX)
AOC Generation Mechanisms

- **H$_2$ oxidizing bacteria**
  - Sacrificial anode (Al or Mg) corrodes producing H$_2$ gas
  - Supports growth of hydrogen oxidizing bacteria
  - Typical Mg-anode: 44” long by 0.7” wide, 490g, 5 yr lifetime

- **160 µg C/L everyday**

Photo Adapted from Edwards et al. 2006
Conclusions

• Temperature is important, but it is more complicated than deciding on a set point

• Recirculating systems have more $\text{H}_2$, less chlorine, less oxygen, higher turbidity and higher metals than standard systems

• Design and operation of hot water systems is important for comfort and health

• Organic matter (food) can be generated in hot water systems
Highlights of:

• Unleaded Brass Performance Research
• Hex Chrome Cr(VI) Issue
• LEED (Building Water Quality)
• Legionella
• Changes in Water Chemistry
Anticipating Challenges Associated with In-Building Disinfection for Control of Opportunistic Pathogens in Premise Plumbing

William Rhoads
Amy Pruden
Marc A. Edwards

Department of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA 24061
A shifting paradigm

- Responsibility for control of opportunistic pathogens is unclear
- Proposed ASHRAE Standard 188 for *Legionella*
- In-building disinfection techniques
  - Thermal/Chemical disinfection
Proposed ASHRAE Standard 188

- First legal requirement for *Legionella* outbreaks
  - Defines responsibilities of stakeholders
  - Requires certain buildings to prepare for an outbreak before one occurs
- Imperfect
  - Encourages in-building disinfection methods
  - Identifies risk factors instead of monitoring
ASHRAE Recommendations
(ASHRAE Guideline 12-2000)

• Thermal disinfection
  • 60°C in HWH tanks
  • 51°C throughout entire hot water system
  • < 25°C in cold water systems

• Chemical Disinfection
  • Chlorine
  • Chloramine
  • Chlorine dioxide
  • Copper-silver ionization
  • UV irradiation
  • Ozone
Thermal disinfection

• EPA: 48°C in HWH tanks
• Easy to apply, but expensive
• ASHRAE: 51°C throughout entire system can’t be maintained
• Abiotically increase corrosion rates?
  – Pinhole, erosion corrosion?
• Scaling
  – Precipitation of CaCO₃
Higher Temps = More Hard Water Scaling

* Decreased solubility with increasing temperature

** Increase energy demand – e.g. 30% (Isaacs and Stockton, 1981)
Influent chlorine residual > 0.5 mg/L?*

- Yes → Residual carries through hot water system and distal taps
- No → Consider selection and dosing of disinfectant

  - Yes → Selection compatible with existing plumbing?
    - Yes → Implement disinfection strategy
    - No → Water utilities disinfection may be adequate
  - No → Water utilities disinfection may be adequate
Chlorine and Chloramine

- Over 100 years of experience

- Stability of \( \text{NH}_2\text{Cl} \)
  - lost in PP

- Rapid reactions
  - New Cu pipes
  - Nitrification

![Graph showing chloramine decay over time](chart.png)
Chlorine Dioxide

- Commercial kits available provide ease of use
- USEPA MRDL 0.8 mg/L ClO₂
  - Chlorite formation
- Field studies:
  - Legionella eliminated after 1 month¹
  - 17 month study observed high efficacy in Legionella³
  - Effective for dead ends²
  - Less effective with high temps, TOC, iron and corrosion scale⁴,⁵

Copper-Silver

- Requires expertise, monitoring\(^5\)
- Discoloration of water or plumbing devices\(^3,4\)
- Deposition corrosion\(^6,7,8\)
- Conflict with Cu levels in sewage\(^1,2\)
- Field studies\(^9,10,11\)
- Effects of pH, alkalinity, phosphates???

Copper-Silver Cont’d

News Update:

Effective February 1, 2013

• Copper-Silver Ionization systems not allowed in European water systems
• No proof of efficacy from manufacturers

http://www.xcenta.co.uk/home/LegionellacontrollImportantinformationforusersandsuppliersofwatertreatmentsystems.html
# Disinfectants in Premise Plumbing

<table>
<thead>
<tr>
<th>Disinfectant/ Pipe Material</th>
<th>Provides Disinfectant Residual</th>
<th>Copper</th>
<th>Iron</th>
<th>Polyvinyl chloride (PVC, CPVC)</th>
<th>Polyethylen (HDPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>Yes</td>
<td>Corrosive; rapid rxn with scale; pitting</td>
<td>Corrosive; rapid rxn with scale</td>
<td>None</td>
<td>Repeat shock treatments damage</td>
</tr>
<tr>
<td>Chloramine</td>
<td>Yes</td>
<td>Corrosive; rapid rxn with scale</td>
<td>Corrosive; rapid rxn with scale</td>
<td>None</td>
<td>??</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>Yes</td>
<td>Corrosive; rapid rxn with scale</td>
<td>Corrosive; rapid rxn with scale</td>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td>Ozone</td>
<td>No</td>
<td>??</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td>Copper-Silver</td>
<td>Yes</td>
<td>Ag corrosive?</td>
<td>Deposition corrosion on galvanized</td>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td>UV</td>
<td>No</td>
<td>None likely</td>
<td>None likely</td>
<td>None likely</td>
<td>None likely</td>
</tr>
</tbody>
</table>
Conclusions

• Direct conflicts between control of OPPPs and other worthy goals such as scalding, disinfection by-products, energy conservation, water conservation and corrosion control

• Water age, disinfectant type, residual levels, and plumbing materials influence OPPP growth
  • Need for research on in-building disinfection systems
QUESTIONS? COMMENTS?

William Rhoads – wrhoads@vt.edu
Amy Pruden – apruden@vt.edu
Marc Edwards – edwardsm@vt.edu