The Effect of Partial Lead Service Line Replacements on Lead Leaching

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If utility exceeds 15 ppb AL, partial pipe replacements may be required up to property line.
Adverse Consequences of Partial Replacements

- Disturbing rust scale (Boyd et al., 2004)
- Galvanic Corrosion (Britton et al., 1981)
- Deposition Corrosion (Britton et al., 1981)
Cincinnati – lead spikes after partial line replacements; lasted 1-4 weeks

“But even after 1 year of sampling, partial lead service line replacement did not show an improvement over keeping a complete line in place.”

(Swertfeger et al., 2006)
Only examined cutting of lead pipe

Observed higher lead release for over 2 weeks

Intermittent Flow: total Pb > 15 ppb after 2 weeks

Continuous Flow: total Pb consistently < 15 ppb after 2 days (high flow) or 6 days (low flow)
Anode

Oxidized

“Sacrificed”

Pb

Cl⁻

SO₄²⁻

Cathode

Reduced

“Protected”

Pb²⁺

“Lewis”

Acid

2e⁻

Cu

O₂

OH⁻

Lower pH

Higher pH
“...the pH drop near the surface of the leaded materials in poorly buffered waters increases lead solubility”

Dudi, 2004
Deposition Corrosion

Water flow

Cu²⁺

O₂ + 4e⁻ → 2OH⁻

Cu²⁺ + 2e⁻ → Cu

Galvanic Cells

New Cu Pipe

Pb Pipe
Early work on galvanic corr. and lead

- “…solution of lead was assisted by contact with other metals” such as copper-lead connections (Wolffhugel, 1887)

- “…in practice, contact with iron pipes, solder, etc., is an important factor in assisting the attack on lead by water.” (Lindsay, 1859)

- “…galvanic action is a most powerful agent in promoting the corrosive action of certain waters upon lead” (Stirling, 1859)
Galvanic corrosion important for roofs

Urban rainfall on roofs
  - Large increase in Pb corrosion rates if Pb connected to Cu

Some increase in marine atmosphere (higher Cl)

(Kucera et al., 1982)
Britton and Richards, 1984

- 186 – all or some Pb service lines
- 69 – had at least 1 Cu/Pb connection
“…abnormally erratic or much higher than normal lead concentrations” when Pb connected to Cu

“Occasionally the insertion of copper pipe can produce particularly bad results and despite satisfactory pH control it may be impossible to obtain satisfactory samples.”

“…the contribution to the water lead concentration from the area around the lead/copper junction is obvious.”
What are the practical concerns related to galvanic corrosion and PSR?

- Creation of new Pb/Cu junctions
- Placing copper before lead in flow sequence
## Scenarios

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Galvanic Junction(s)</th>
<th>Copper Deposition on Lead?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb - PVC or dielectric</td>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>Service House Pb Cu</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Service Cu(^{2+}) Pb Cu</td>
<td>2</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Chloride to Sulfate Mass Ratio (CSMR)

Sample Calculation

\[
\text{Chloride to Sulfate Mass Ratio (CSMR)} = \frac{[\text{Cl}^-]}{[\text{SO}_4^{2-}]} = \frac{10 \text{ mg/L Cl}^-}{20 \text{ mg/L SO}_4^{2-}} = 0.5
\]
Causes for Concern: High CSMR

- English studies measured galvanic current and voltage in connections of lead solder to copper
  - Oliphant (1983) and Gregory (1985)
  - Dodrill & Edwards (1995) and Triantafyllidou (2007): more lead with higher chloride and lower sulfate
- Pb action level exceedences when coagulant changed from alum to PACl, isolated cases of lead poisoning
Experimental Plan

- Deposition corrosion from Cu$^{2+}$
  - Stagnant
  - Flow
- Galvanic corrosion (Pb/Cu)
- Simulated small scale partial replacement
Experimental Design: Cu^{2+} Deposition Corrosion

<table>
<thead>
<tr>
<th></th>
<th>Cl(^{-}) (mg/L)</th>
<th>SO(_4^{2-}) (mg/L)</th>
<th>CSMR</th>
<th>pH</th>
<th>Alkalinity (mg/L CaCO(_3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>High CSMR Water</td>
<td>129</td>
<td>8</td>
<td>16</td>
<td>8.3</td>
<td>10</td>
</tr>
</tbody>
</table>

- Free chlorine and chloramine (4 mg/L Cl\(_2\))
Experimental Design: 

Cu²⁺ Deposition Corrosion

**Stagnant:**
- 3 Replicates
- Dump & Fill 3 X/week

![Image of a pipe with copper ions and Pb pipe]
Experimental Design: Cu\textsuperscript{2+} Deposition Corrosion

**Flowing:**
- Continuous flow
- Water change once/wk

- 0 or 5 mg/L Cu\textsuperscript{2+}
- 4 mg/L free chlorine or chloramine

\[ Q = 2.75 \text{ gpm} \]
Cu$^{2+}$ Deposition Corrosion – Stagnant *(Chloramine)*

**Avg. of Weeks 8-15**

![Graph showing the total lead released (ppb) for different amounts of Cu$^{2+}$ added.](image)
Cu$^{2+}$ Deposition – Flowing Free Chlorine

![Graph showing Cu$^{2+}$ deposition and free chlorine levels over time.](image-url)
**Cu²⁺ Deposition Corrosion**

**Conclusions**

- Trace levels of Cu²⁺ (even 0.03 mg/L) increased lead release from lead pipe w/ no galvanic connection to Cu.
- Deposition corrosion significant concern in terms of lead leaching as per prior research.
- Putting a copper pipe before a lead pipe in the flow path, as occurs in partial replacement, is a concern.
Mechanisms of Galvanic Corrosion (Pb Pipe – Cu Pipe)

New vs. Aged Pb Pipe

CSMR
Experimental Design

4 in

2 ft
Experimental Design

- New Pb Pipe
- Passivated Pb Pipe
  - Simulate pipes exposed to free chlorine
  - Pb(IV) scaling
Aged and New Pb
(End of Study)
**Water Chemistry**

*pH 8.3*

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<th>SO₄²⁻ (mg/L)</th>
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**Disinfectants:**

- Free chlorine & chloramine
Experimental Design

- Dump and fill
- 3 X / week

Measurements:
- Pb and other metals
- Galvanic current
- Local pH
CSMR – Pb Pipe Alone

Age of Lead (Not Connected to Cu)

- New Pb Pipe
- Passivated Pb Pipe

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<th>Age of Lead (Not Connected to Cu)</th>
<th>Total Lead (µg)</th>
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<td>Low CSMR</td>
<td>Avg. 12 weeks</td>
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<tr>
<td>High CSMR</td>
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- Low CSMR
- High CSMR

- New Pb Pipe
- Passivated Pb Pipe
Effect of Galvanic Connection (New Pb Pipe)

- New Pb without Cu Pipe
- New Pb with Cu Pipe

![Graph showing the effect of galvanic connection on new lead levels.](image)

**New Lead**

- Low CSMR
- High CSMR

**Total Lead (µg)**

- 1,000
- 4,000
- 5,000
- 6,000

**Average 12 weeks**

- 57 X increase
- 10 X increase
Effect of Galvanic Connection
(Passivated Pb Pipe)

![Graph showing the effect of galvanic connection on lead levels over 12 weeks. The graph compares 'No Cu Pipe' (blue line) and 'With Cu Pipe' (red line). The y-axis represents total lead (µg) and the x-axis represents week number. There are peaks in lead levels between weeks 5 and 8, particularly with the 'With Cu Pipe' condition.]
Effect of Galvanic Connection (Passivated Pb Pipe)

No Cu Pipe

With Cu Pipe

(free chlorine)

Total Lead (µg)

Week
1) pH changes at junction
2) Galvanic current vs. time
pH Measurements

pH drop due to galvanic connection

Graph showing pH measurements with a significant drop near the junction of lead and copper, indicating a high CSMR, NH2Cl.
pH vs. Galvanic Current

\[ y = 0.047x + 11.1 \]
\[ R^2 = 0.835 \]
Simulated Small Scale Partial Replacements
3 ft

Pb Pipe

Cu Pipe
Effect of Cu:Pb Length after Partial Lead Service Line Replacements on Lead Release

0% Cu (i.e. 100% Pb) = Before Replacement

17% Cu

50% Cu

67% Cu

83% Cu

100% Cu = Full Replacement
# Water Chemistry

**pH 8.0**

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Dump & fill 3 X /week

Low CSMR – Weeks 1-11

High CSMR – Weeks 12-24
Effect of Galvanic & Deposition Corrosion on Pb Release – Low CSMR

![Graph showing the effect of copper content on Pb release over time. The graph compares Pb release for 0% Cu and 100% Cu over a period of 12 weeks. The 0% Cu line shows a significant decrease in Pb release over time, whereas the 100% Cu line remains nearly constant.]
Effect of Galvanic & Deposition Corrosion on Pb Release – Low CSMR

Low CSMR = Low Galvanic Corrosion

Time (Weeks)

Pb (ppb)
% Pb increase – Low CSMR

% Increase in Pb Release Compared to Pure Pb Pipe

% Cu after Partial Replacement

17% 50% 67% 83%
Effect of Galvanic & Deposition Corrosion on Pb Release – High CSMR

![Graph](image-url)
Effect of Galvanic & Deposition Corrosion on Pb Release – High CSMR

High CSMR = High Galvanic Corrosion

- 0% Cu
- 17% Cu
- 50% Cu
- 67% Cu
- 83% Cu
- 100% Cu

Pb (ppb)

Time (Weeks)

5 X

Graph showing the effect of different copper concentrations on Pb release over time.
• 17% Cu / 83% Pb was the worst case
• Less copper relative to lead worsened galvanic corrosion
Conclusions

- Cu$^{2+}$ in water increases Pb in water (deposition corrosion)
- Galvanic corrosion of Pb/Cu couples can be significant
  - Lower pH and higher Cl$^-$ at Pb junction during stagnation
  - Pb is sacrificed
Conclusions

- Simulated partial service line replacement
  - Higher Pb (> 200%) in low CSMR water
  - Higher Pb (>165%) in high CSMR water
  - Short length of Cu relative to Pb had highest Pb release
First Definitive Laboratory Data

indicating potential long-term detriments from galvanic and deposition corrosion arising from partial replacement.
Lead in Water of Service Line (ppb) vs. % Lead Pipe Replaced with Copper

- Blue line: No galvanic or deposition corrosion
- Red line: Galvanic or deposition corrosion

8X increase in Lead in Water of Service Line when 20% of Lead Pipe is replaced with Copper.

14X increase in Lead in Water of Service Line when 80% of Lead Pipe is replaced with Copper.
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Questions?

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