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Colloidal Lead Release in Drinking Water Distribution System:

An Ignored and Difficult Aspect of Lead Release Control

Haizhou Liu, Gregory Korshin, John Ferguson

University of Washington, Seattle

Background on lead in drinking water

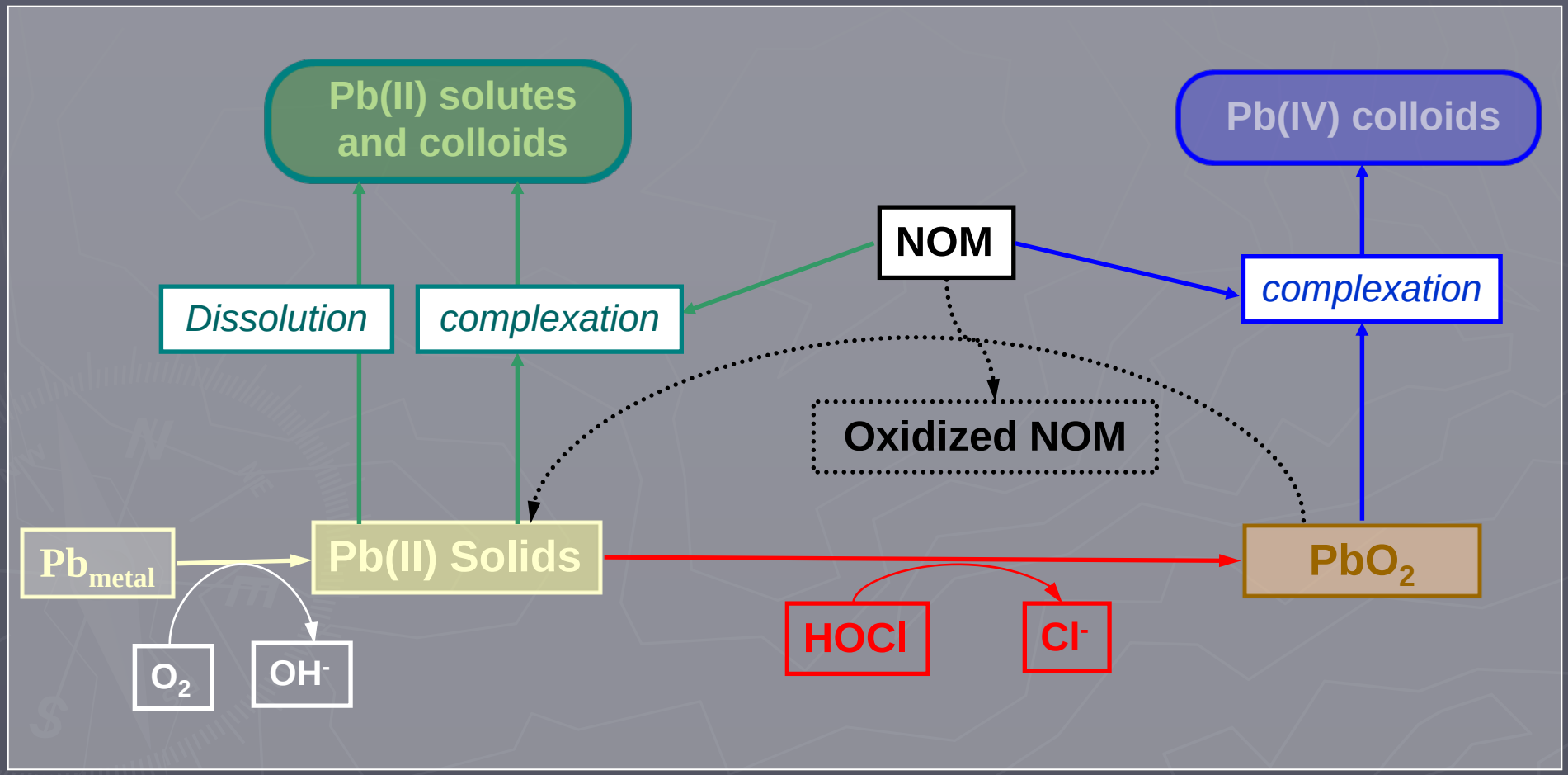
- **Lead regulation**
  - Blood lead level is inversely proportional to IQ
  - Maximum contaminant level goal is zero
  - Drinking water action level is 15 μg/L
- **However, there is a long history of application of lead in drinking water distribution system**
  - Pure lead pipes were installed in many North American cities more than 100 years ago.
  - Other lead-bearing materials still widely exist, such as lead-tin solder and lead-containing brass.

Historical application of lead

Table: Existence of lead pipes as the water service line in the 20 largest U.S. cities in 1900.

City	Population	Pipes	City	Population	Pipes
New York, NY	3,437,202	Lead	Pittsburgh, PE	321,616	Lead
Chicago, IL	1,698,575	Lead	New Orleans, LA	287,104	Lead
Philadephia, PE	1,293,697	Lead/Iron	Detriot, MI	285,704	Lead
St. Louis, MO	575,238	Lead	Milwaukee, WI	285,315	Lead
Boston, MA	560,832	Lead	Washington, DC	278,718	Lead/Iron
Baltimore, MD	508,957	Iron	Newark, NJ	246,080	Lead
Cleveland, OH	381,768	Lead	Jersey City, NJ	206,433	n/a
Buffalo, NY	352,387	Lead	Louisville, KT	204,731	Lead
San Francisco, CA	342,782	Lead/Iron	Minneapolis, MN	202,718	Lead
Cincinnati, OH	325,902	Lead	Providence, RI	175,597	Lead

Lead release in drinking water distribution system



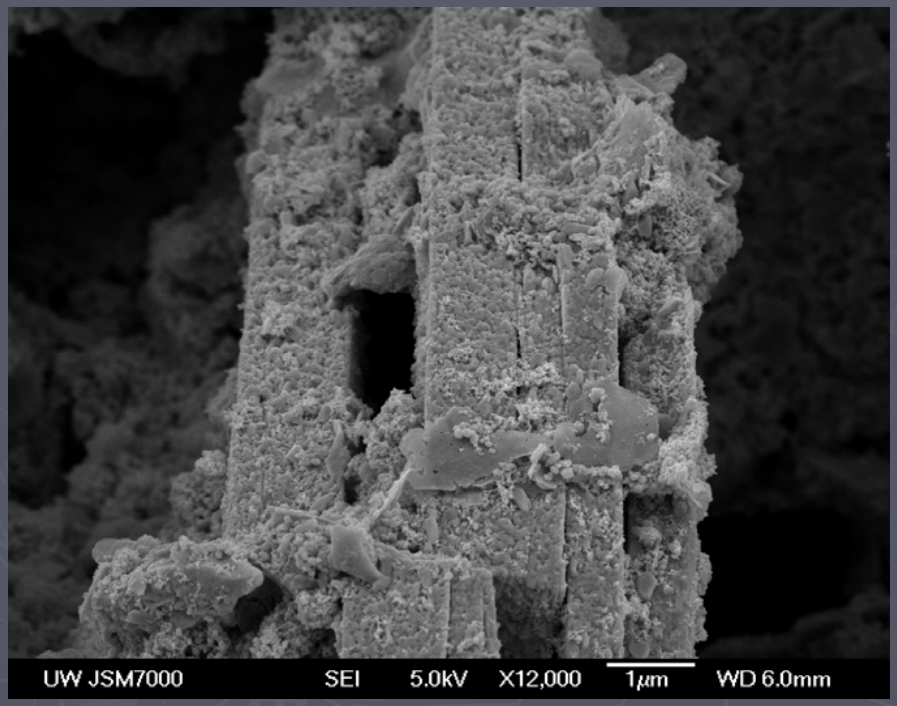
Lead(II) compounds

- **Typical lead(II) compounds found on the surface of lead-containing materials**
  - Hydrocerussite: $Pb_3(CO_3)_2(OH)_2$
  - Cerussite: $PbCO_3$
  - Lead hydroxide: $Pb(OH)_2$
  - Lead oxide: PbO
  - Hydroxypyromorphite: $Pb_5(PO_4)_3OH$
  - Chloropyromorphite: $Pb_5(PO_4)_3Cl$

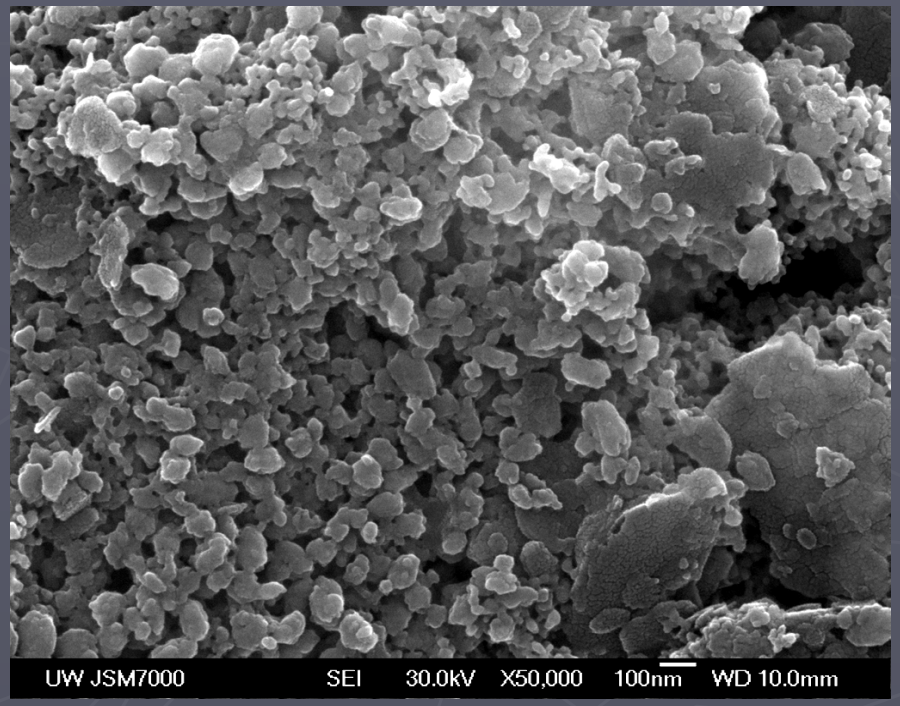
Lead release control issues

- **Traditional control strategies**
  - pH and alkalinity adjustment
  - Addition of phosphate corrosion inhibitors
  - Based on equilibrium Pb(II) solubility
- **Limitations**
  - Only “true soluble” lead(II) is targeted
  - “Colloidal lead” which can contribute to a very large fraction of aqueous lead, especially particles with size <0.45μm, is ignored and not controlled
  - Impacts of disinfectants and lead(IV) are not explored

Lead(II) and Lead(IV) in corrosion scales



Untreated lead pipe interior



Acid-treated lead pipe interior

Unexpected events associated with colloidal lead release

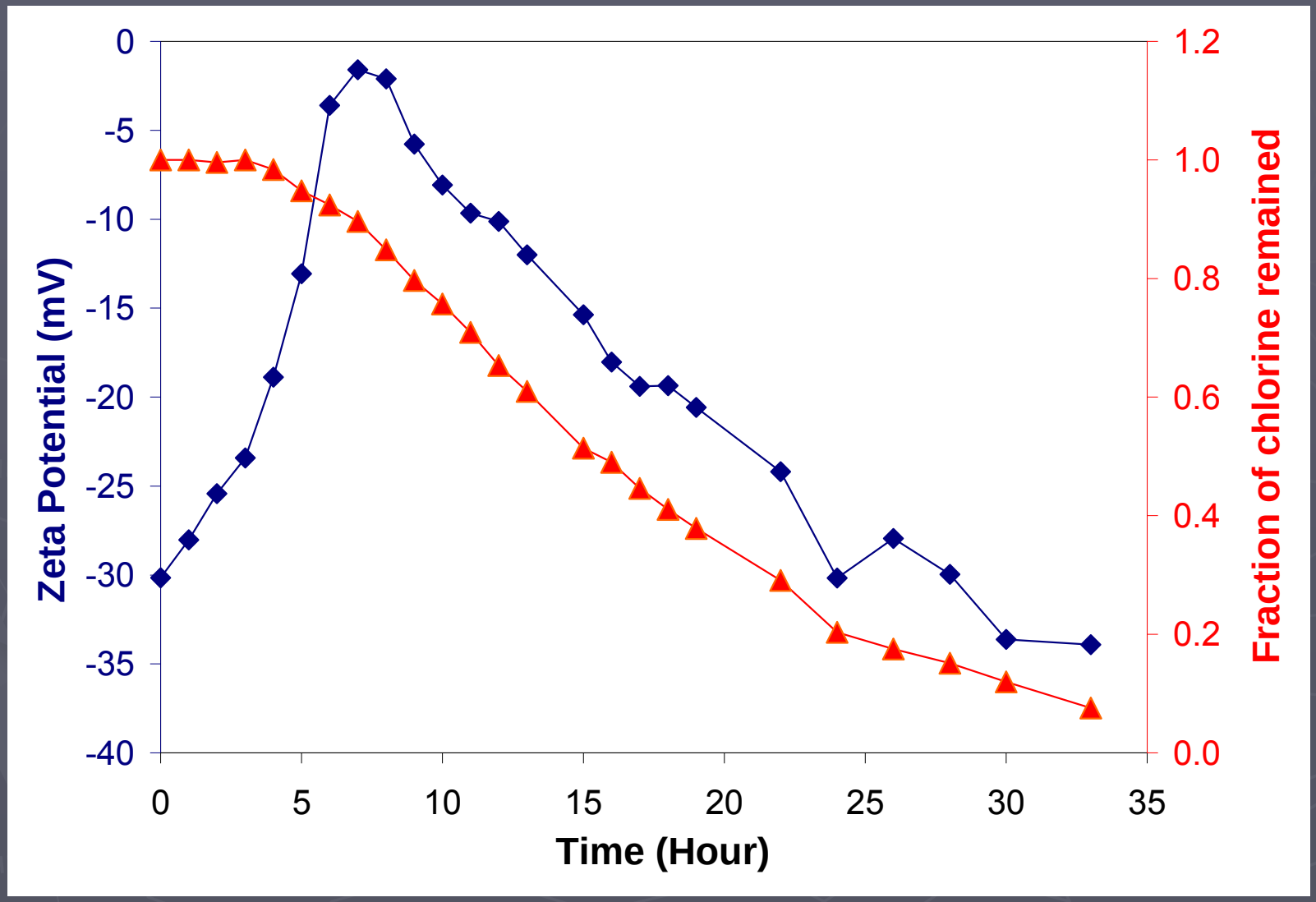
- **Washington, DC**
  - Switch of chlorine to chloramine
  - Colloidal mobilization of PbO_2 by NOM
  - Alleviation by phosphate addition

- **Greenville, NC**
  - Switch of coagulant to $FeCl_3$
  - Occurrence of more particulate lead
  - No benefit of phosphate addition

Research objectives

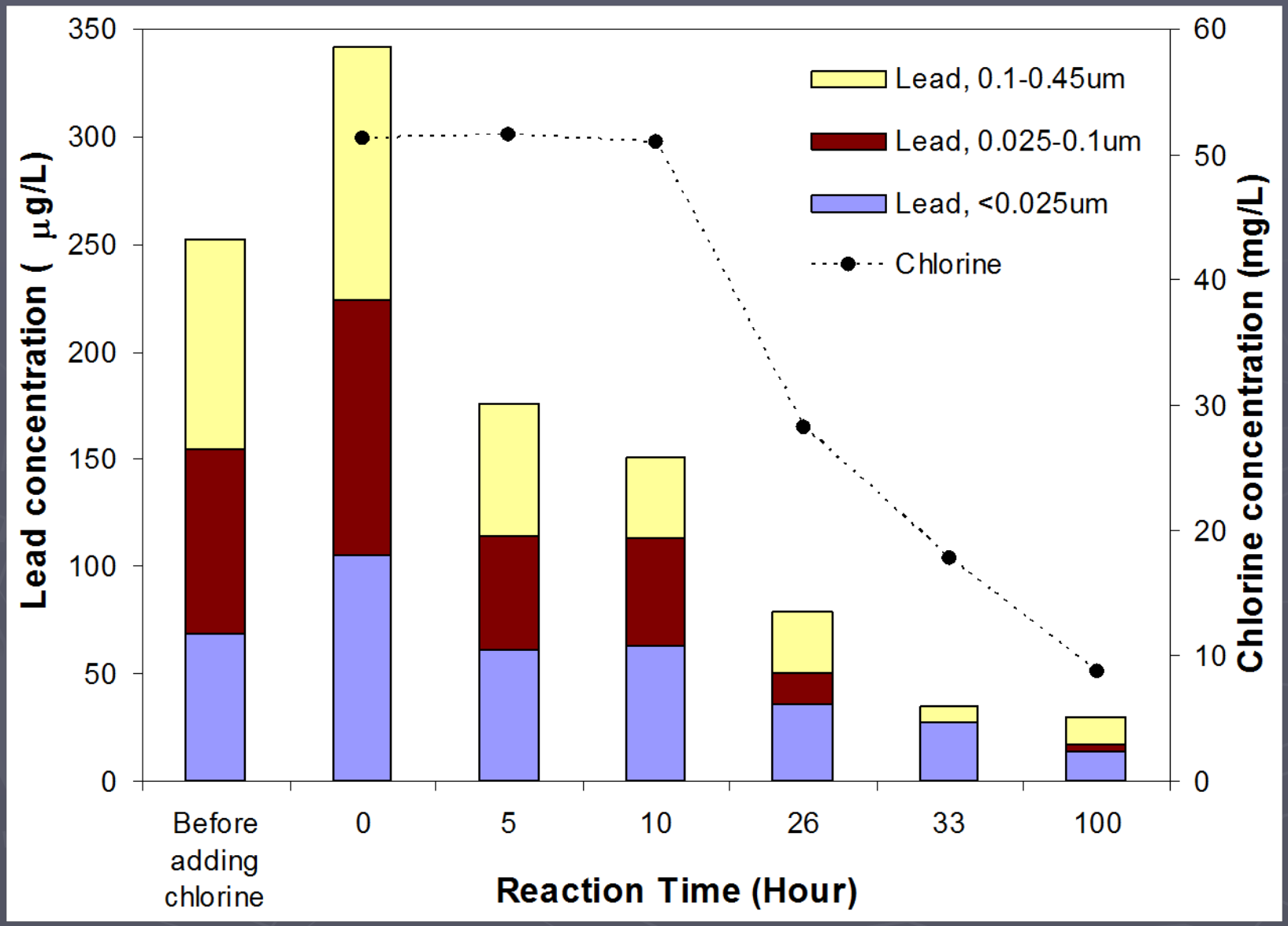
- Understand colloidal lead property and its contribution to overall lead release during Pb(II) solid oxidation by chlorine to form PbO_2.
- Explore changes of colloidal PbO_2 properties in the presence of NOM and by the addition of phosphate inhibitors
- Examine the lead release and colloidal stability of lead phosphate solid phase.

$$Pb_3(CO_3)_2(OH)_2 + 3HOCl + H_2O \rightarrow 3PbO_2 + 3HCl + 2H_2CO_3$$

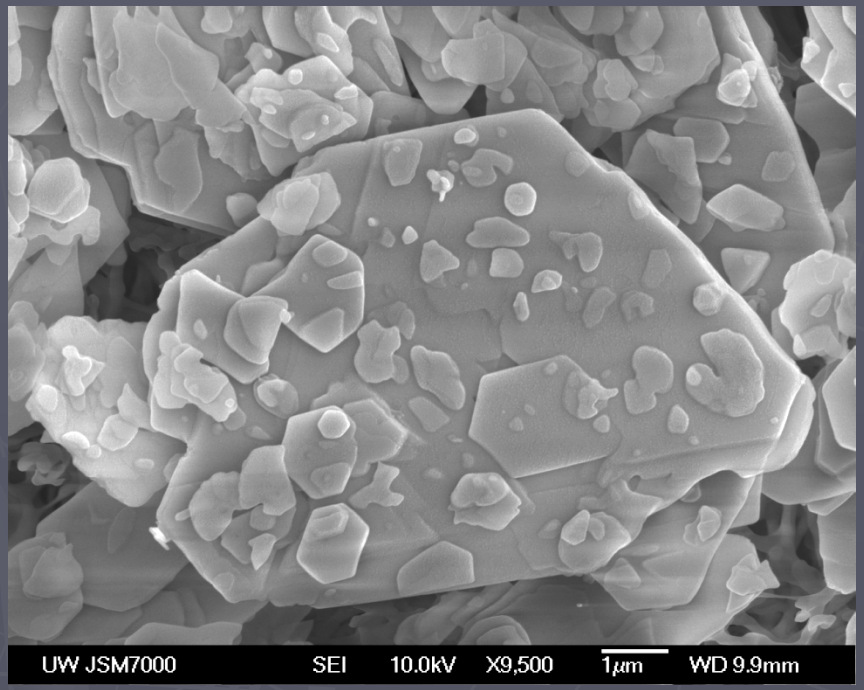


Liu; Korshin; Ferguson. *Environ. Sci. Technol.* **2008**, *42* (9), 3241-3247.

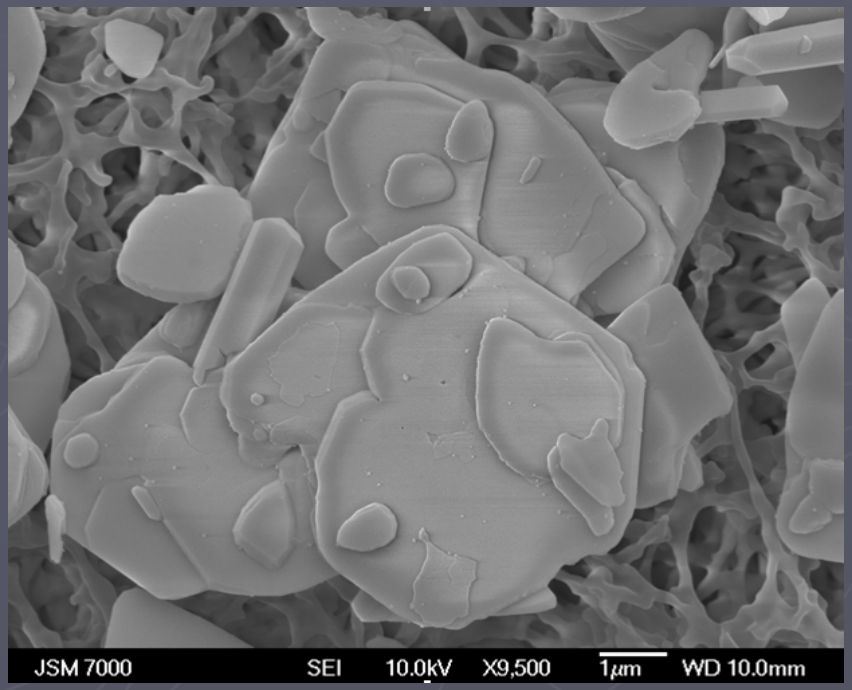
Fractionation of colloidal lead



Morphological Analysis



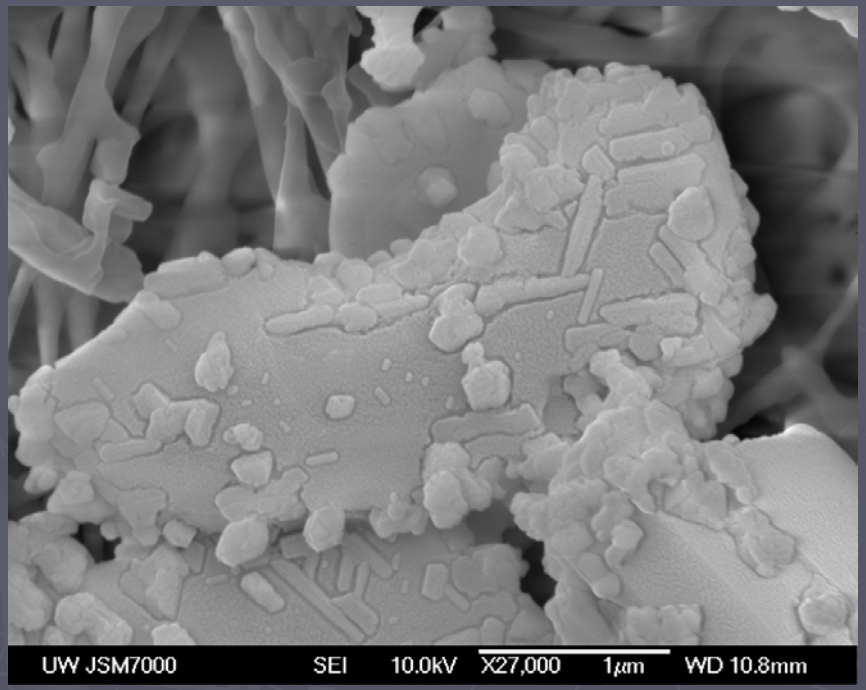
Initial hydrocerussite



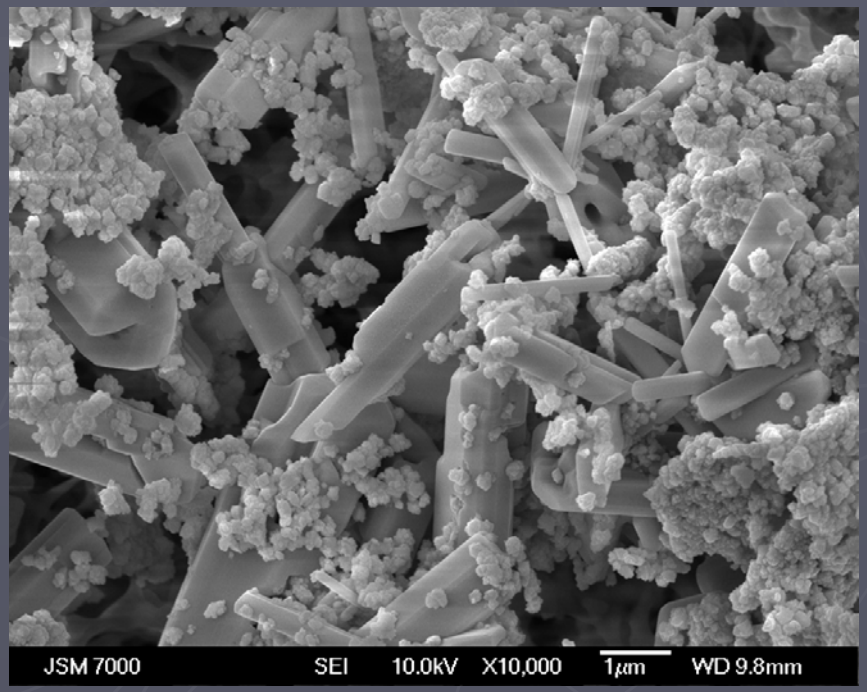
Lag phase

Rapid decrease of colloidal lead release

Morphological Analysis

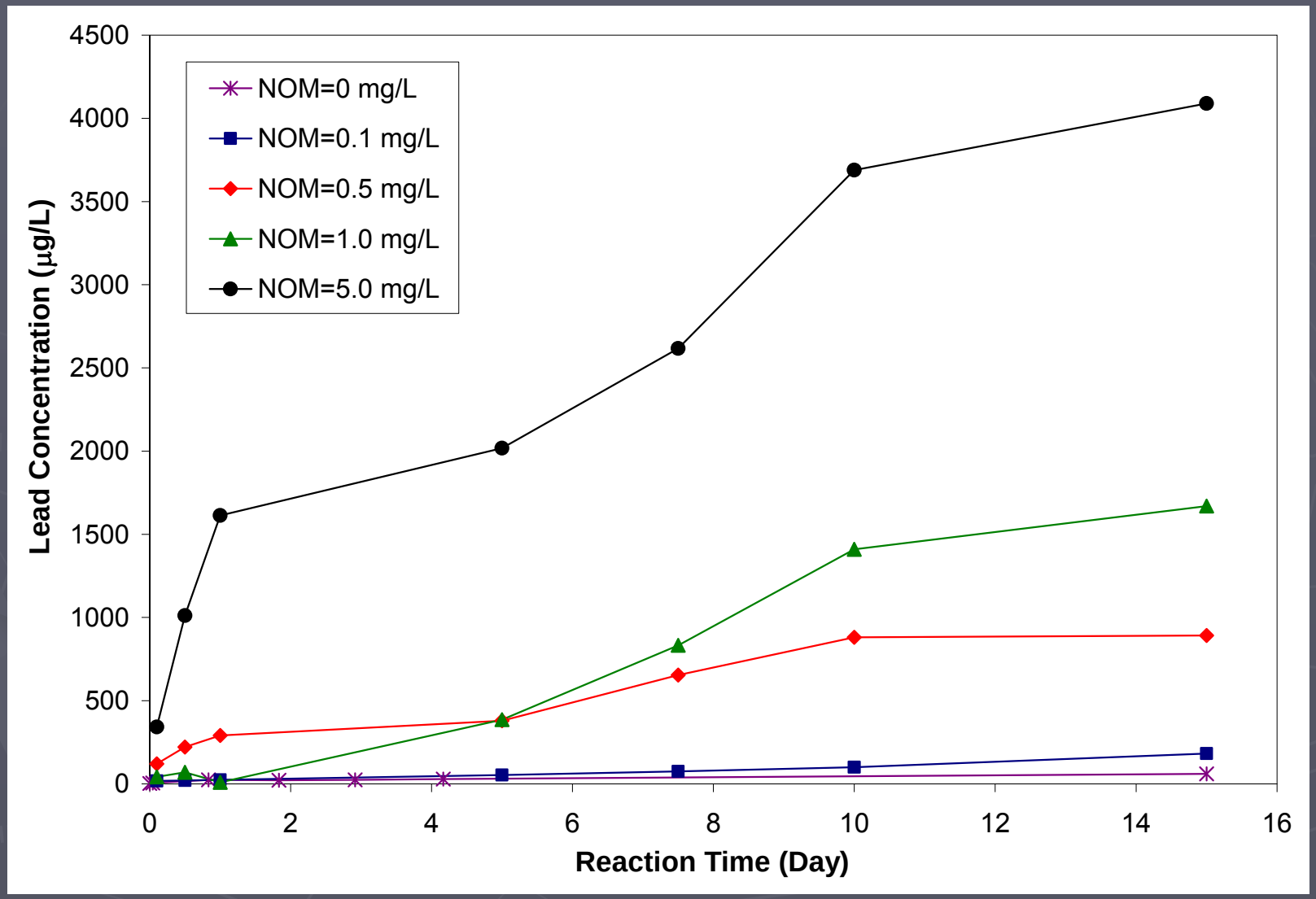


At the end of lag phase



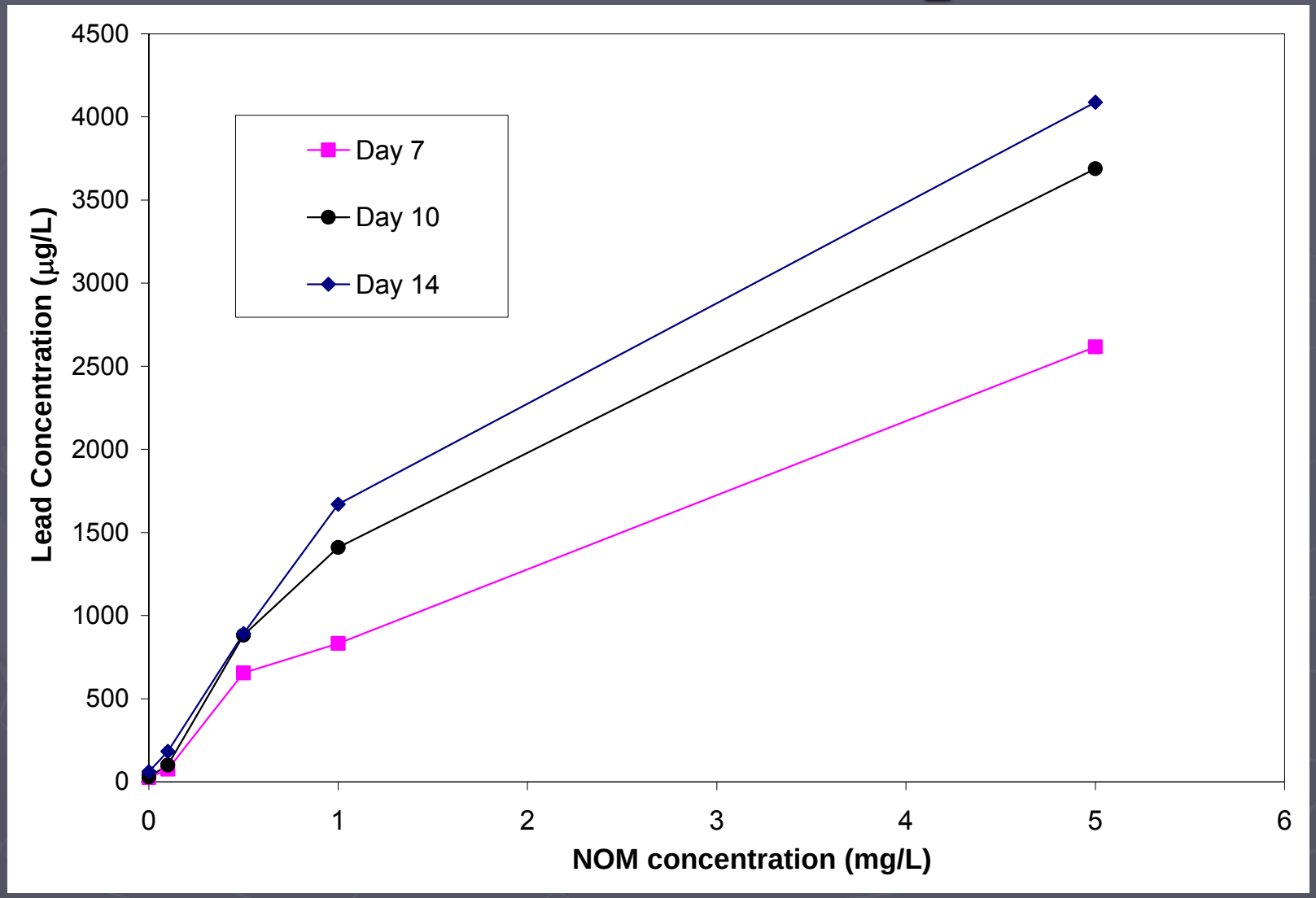
End of reaction

Impact of NOM on colloidal lead release from PbO_2



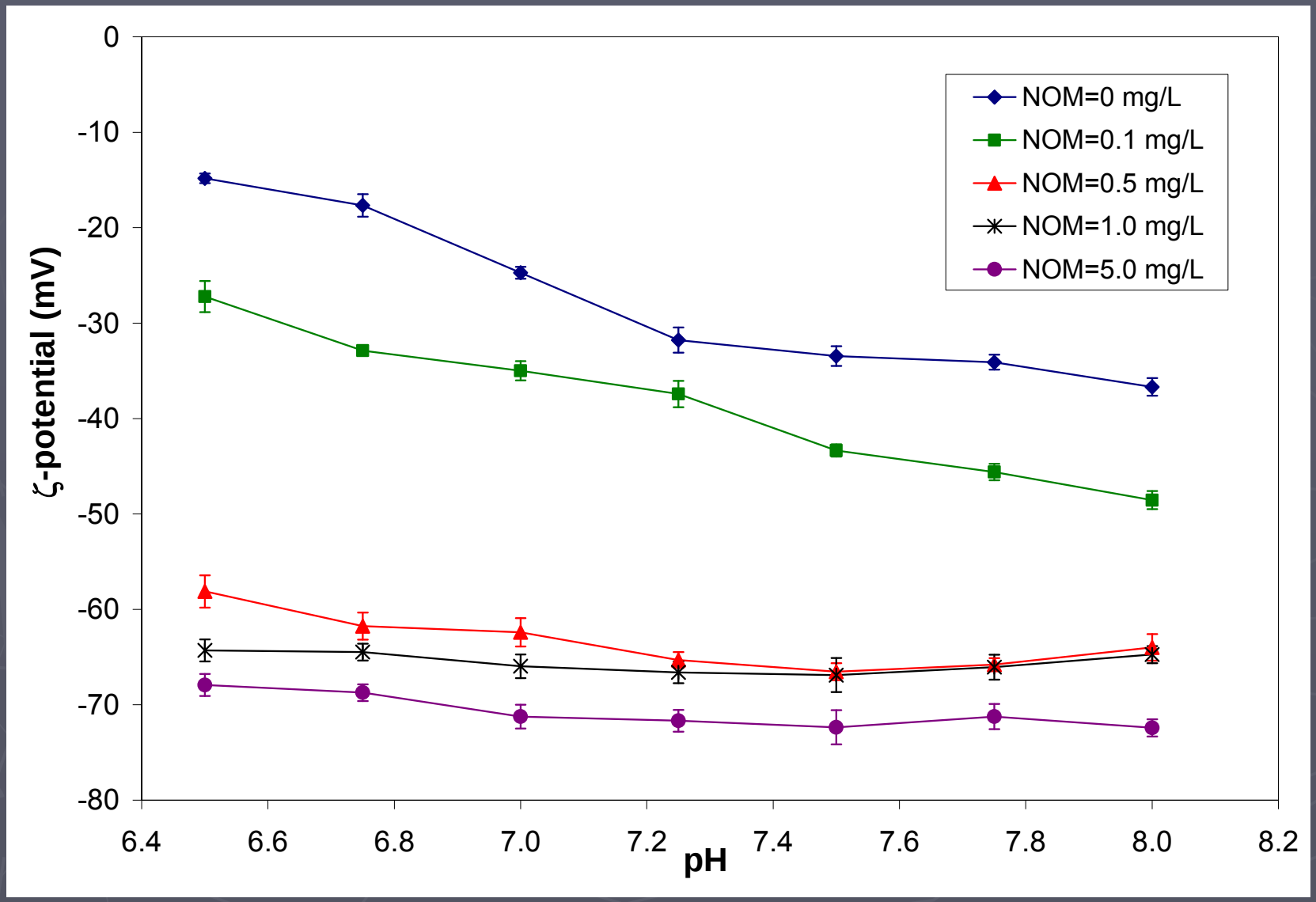
PbO_2=140 mg/L, alkalinity=50 mg/L, pH=7.5

Impact of NOM on colloidal lead release from PbO_2



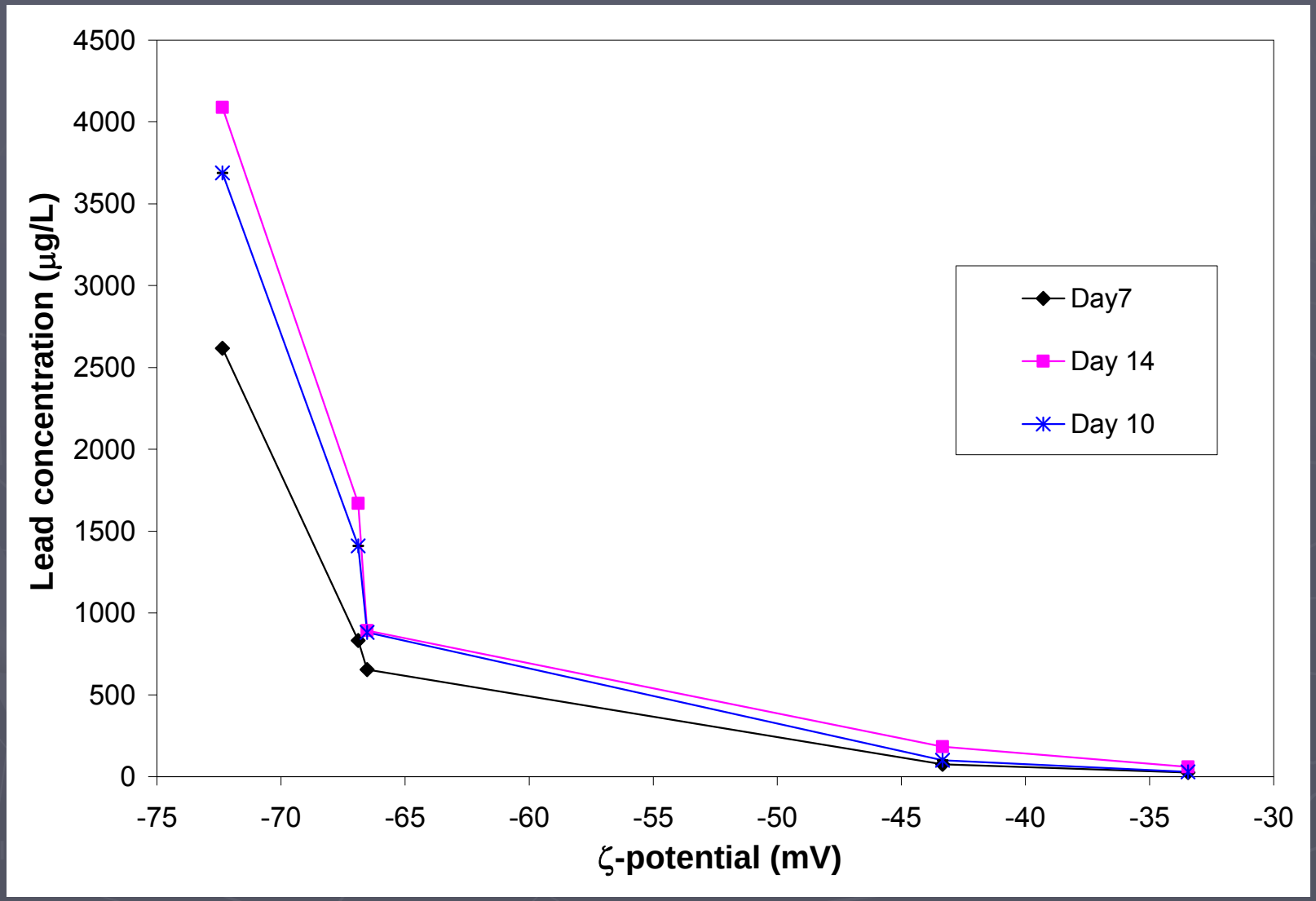
PbO_2=140 mg/L, alkalinity=50 mg/L, pH=7.5

Impact of NOM on PbO_2 colloidal property



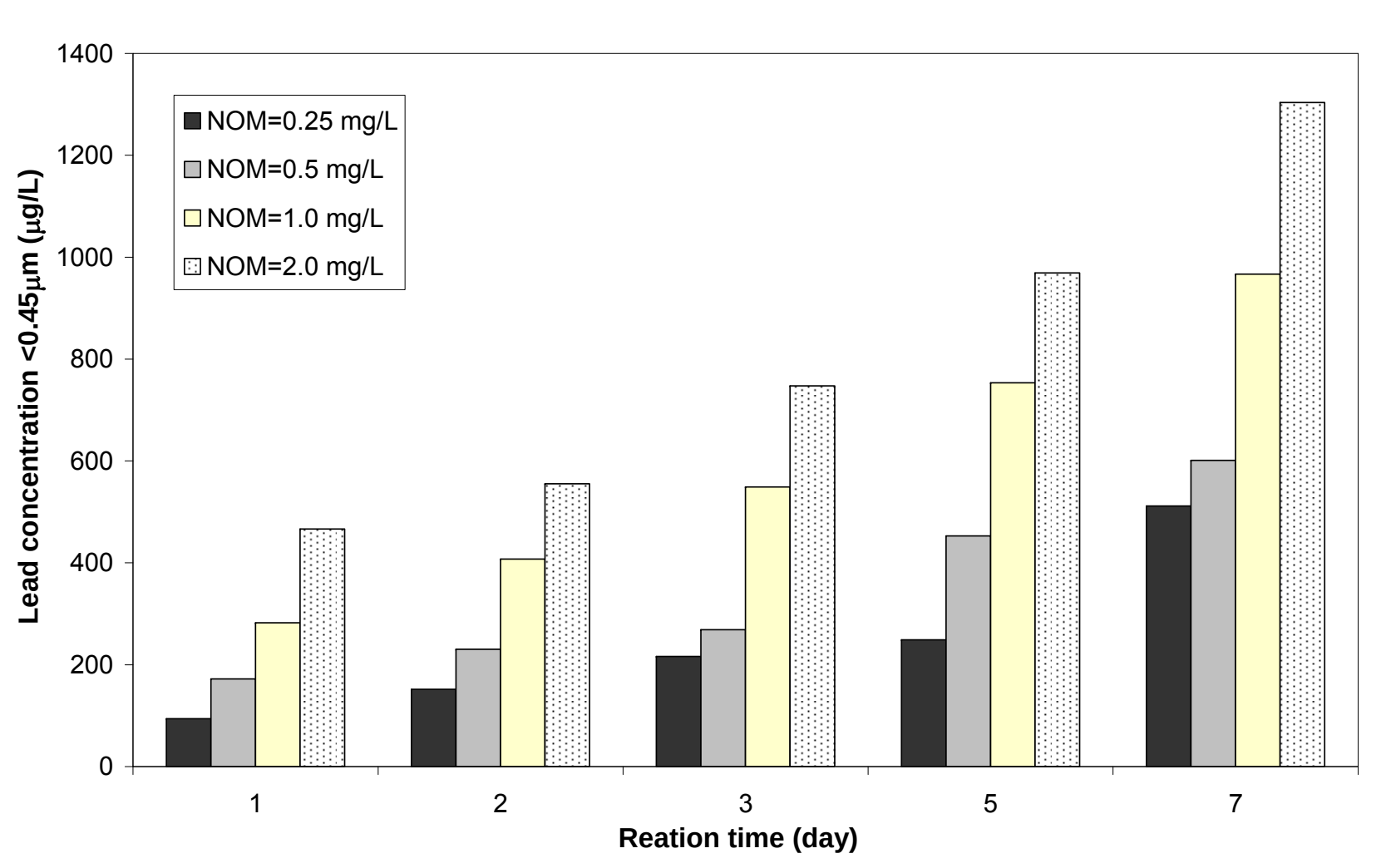
PbO_2=140 mg/L, alkalinity=50 mg/L

Correlation between ζ-potential and lead release in the presence of NOM



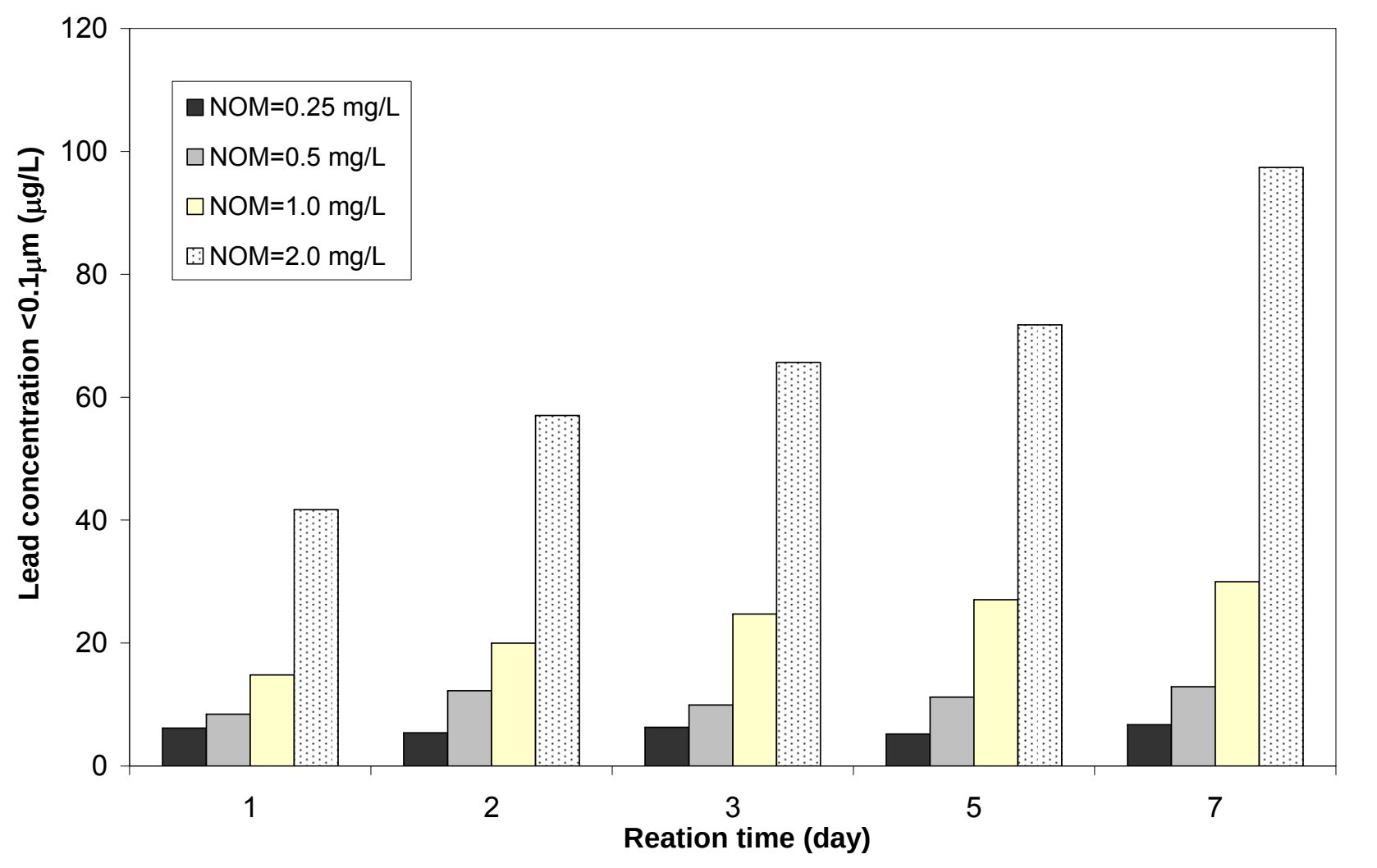
PbO_2=140 mg/L, alkalinity=50 mg/L, pH=7.5

Effects of NOM on colloidal lead release from PbO_2 (<0.45μm)



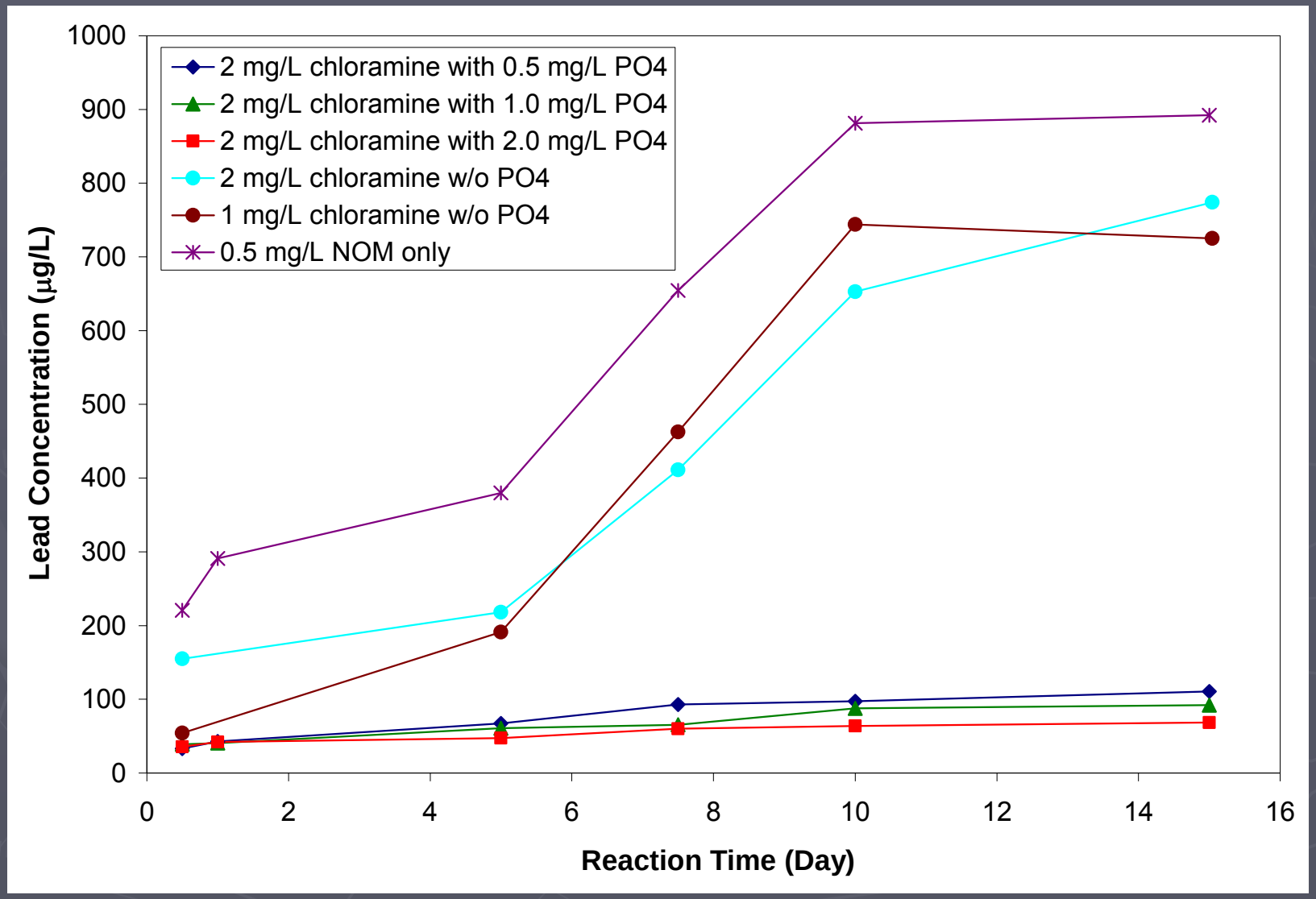
PbO_2=50 mg/L, alkalinity=50 mg/L, pH=7.5

Effects of NOM on colloidal lead release from PbO_2 (<0.1μm)



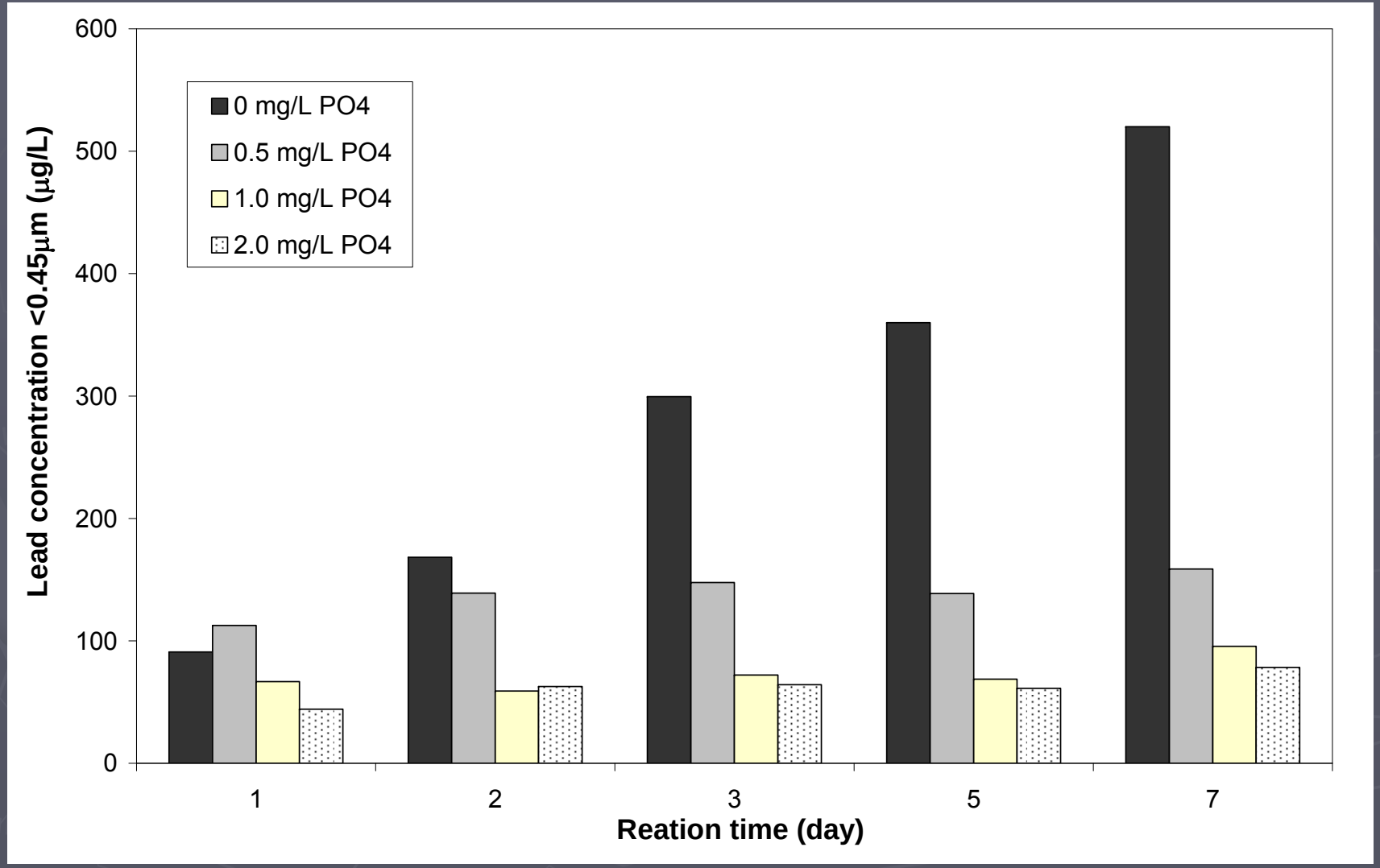
PbO_2=50 mg/L, alkalinity=50 mg/L, pH=7.5

Effects of chloramine on colloidal lead release from PbO_2



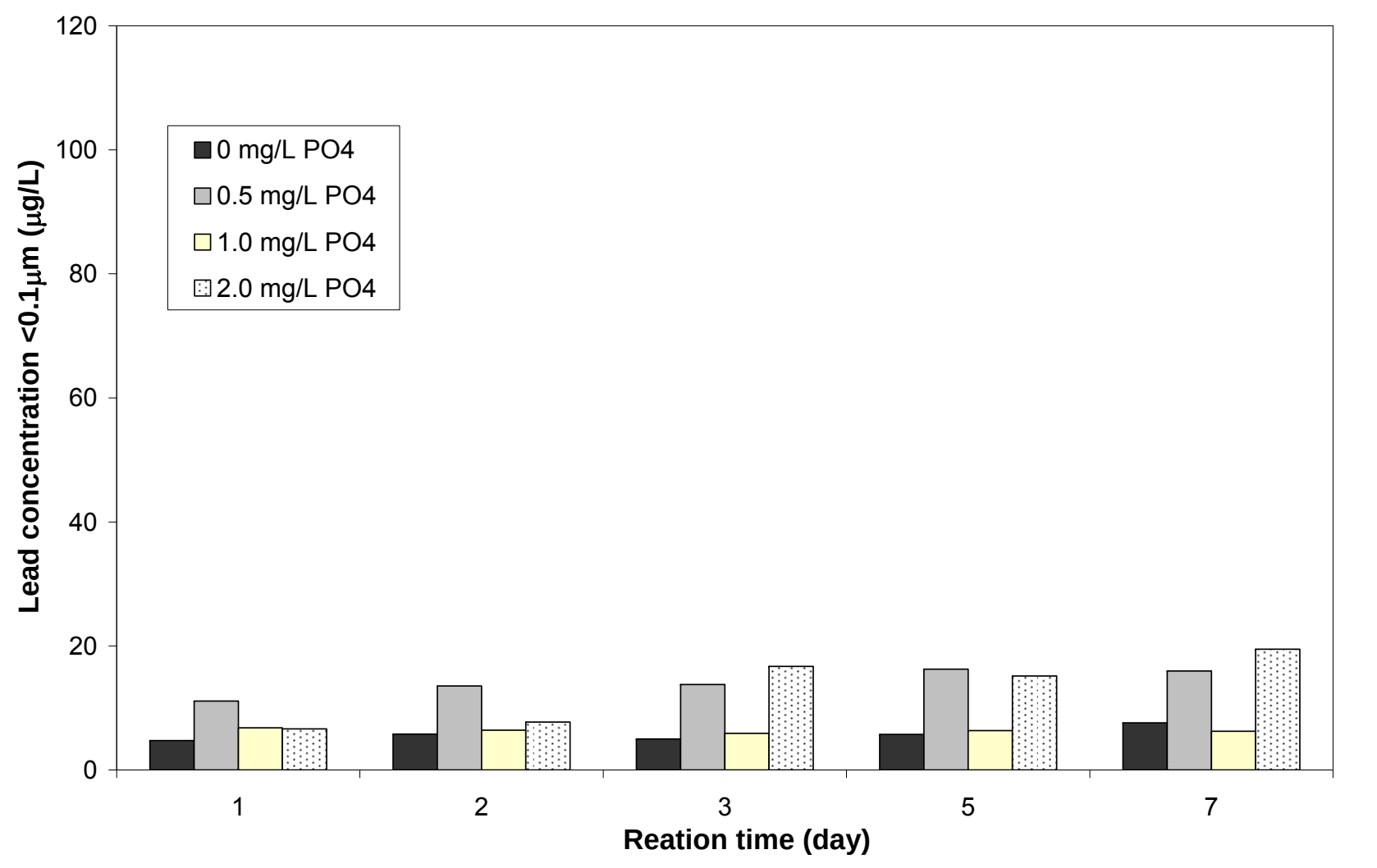
PbO_2=140 mg/L, alkalinity=50 mg/L, pH=7.5, NOM= 0.5 mg/L

Effects of adding phosphate on colloidal lead release from PbO_2 (<0.45μm)



PbO_2=50 mg/L, alkalinity=50 mg/L, chloramine=2 mg/L, pH=7.5

Effects of adding phosphate on colloidal lead release from PbO_2 (<0.1μm)



PbO_2=50 mg/L, alkalinity=50 mg/L, chloramine=2 mg/L, pH=7.5

Conclusions

- Contribution of colloidal lead to operationally defined “soluble” lead can not be ignored. Chlorine oxidation can decrease Pb(II) colloids.
- PbO_2 particles undergo colloidal dispersion in the presence of natural organic matter. Colloidal lead with size between 0.1 and 0.45 μm predominates lead release.
- Addition of phosphate greatly decreases colloidal lead release from PbO_2 in the presence of NOM, but not too much impact on the “true soluble” lead.

Acknowledgement

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Questions