BIOREMEDIATION OF PERCHLORATE IN GROUNDWATER AND REVERSE OSMOSIS REJECTATES

M. E. Losi, Vitthal Hosangadi, and David Tietje
(Foster Wheeler Environmental Corp., Santa Ana, CA)

Tara Giblin and William T. Frankenberger, Jr.
(University of Calif., Riverside, CA)

Outline

- Introduction
  - Background Information
  - Perchlorate Chemistry
  - Remediation of Perchlorate
  - Objectives of Our Work
- Methodology
  - PBR Specifications
  - Inoculation/Start-up
  - Operation/Analytical
  - General Approach
- Results/Discussion
  - Treatment of Groundwater
  - Treatment of Primary RO Rejectate (RO)
  - Treatment of Secondary RO Rejectate (RO2)
- Summary/Conclusions

Introduction

- Background Information – Perchlorate (ClO_4^-)
  - $NH_4ClO_4(s) \Rightarrow NH_4^+ + ClO_4^-$
  - Strong oxidizer
  - Generally stable/mobile in the groundwater
  - $ClO_4^- \Rightarrow \Rightarrow \Rightarrow \Rightarrow Cl^- + 2O_2$

Introduction (Continued)

Counties with Perchlorate Detections in Drinking Water				
County	**Systems**	**Systems >18 µg L^{-1}**	**Sources**	**Sources >18 µg L^{-1}**
Los Angeles	32	12	96	21
Orange	8	0	15	0
Riverside	4	2	29	5
Sacramento	3	3	15	10
San Bernardino	8	6	32	11
Ventura	1	0	2	0
Total	**56**	**23**	**189**	**47**

California Department of Health Services. 2000. Perchlorate in California drinking water. www.dhs.cahwnet.gov/ps/ddwem/chemicals/perchl/perchlindex.htm.

Introduction (Continued)

- Perchlorate Destruction – ClO_4^- => => => => Cl^- + $2O_2$
  - Non-Biological Reduction:
    - Chemical/electrochemical processes
    - Can be thermodynamically favored, but rate-limited
    - Requires significant energy input (heat/pressure, electrical current) as well as an electron donor
  - Biological Reduction:
    - ClO_4^- serves as a terminal electron acceptor in respiration
    - Energy source (electron donor)
    - Appropriate environmental conditions

Introduction (Continued)

- ClO_4^- Remediation Options: Groundwater, *Ex-Situ*

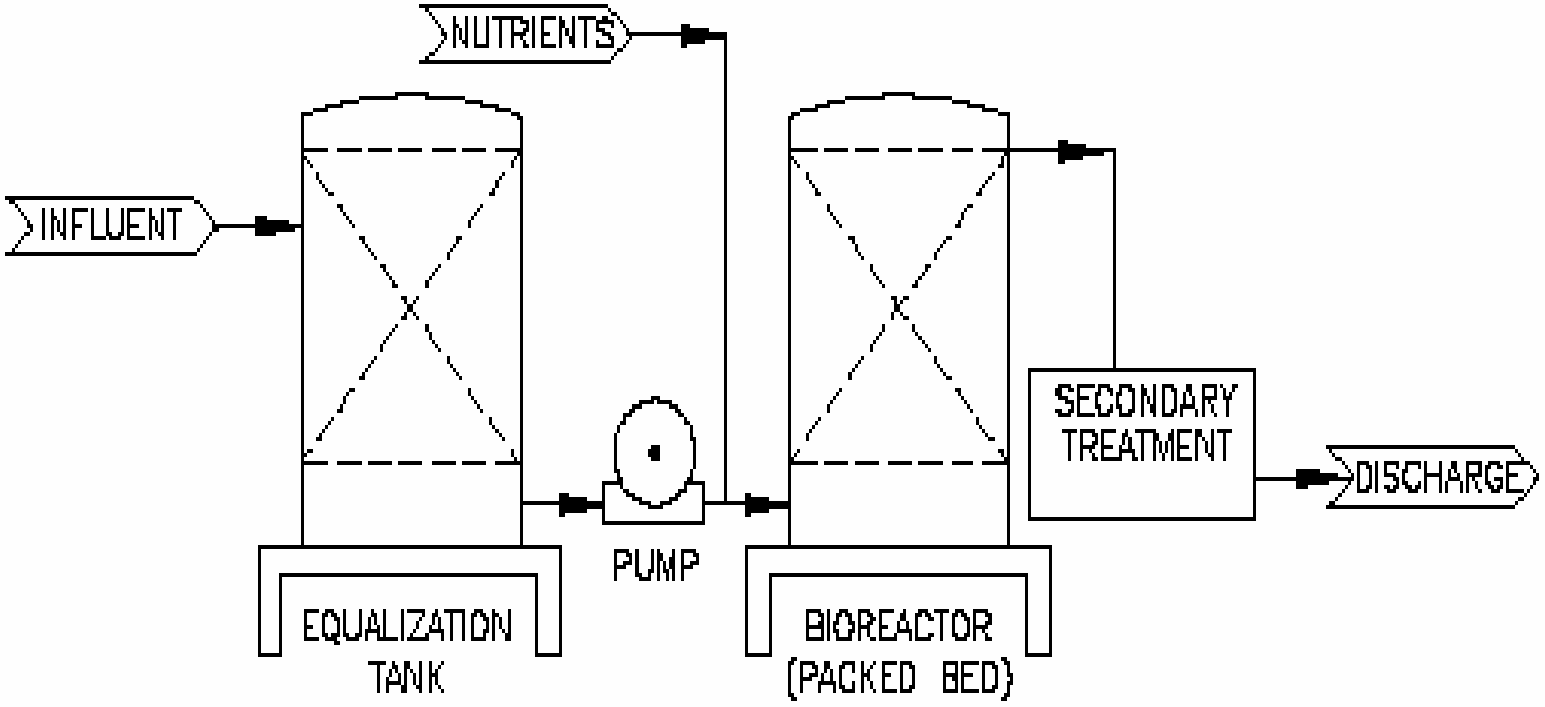
Treatment	Potable Water?	Destructive?	Waste Stream Requiring Further ClO_4^- Treatment	Relative Costs
Ion exchange	Yes	No	Brine (~ 7% NaCl)	High
Reverse osmosis	Yes	No	Rejectate (5-10x TDS of treated groundwater)	High
Biotreatment (bioreactors)	No	Yes	None	Low

Introduction (Continued)

- Bioreactors for the ClO_4^- application
  - CSTR (Coppola/Baxley, Applied Research Associates)
  - Fixed Film Reactors
    - Fluidized bed reactor (Aerojet/US Filter/Envirogen)
    - Fixed or packed bed reactor (Logan, Penn State; Wallace, ARA)

Introduction (Continued)

- Packed Bed Reactor



Introduction (Continued)

- Objectives: Prove the Concept
  - Preliminary evaluate process efficiency:
    - Achievable effluent ClO_4^- levels
    - Estimate residence times
  - Three treatment streams:
    - Actual groundwater
    - Simulated primary RO rejectate (RO)
    - Simulated secondary RO rejectate (RO2)
  - Secondary goal: Fate of NO_3^- and SO_4^{2-}

Methodology

- PBR Specifications

Column Specifications

Parameter	**Specification**
Inside diameter	13.5 cm
Total height	21.4 cm
Bed height	12.5 cm
Total volume	3062 mL
Total bed volume	1789 mL
Pore volume	1236 mL
Packing material	Celite (R-635)

Methodology (Continued)

- Inoculation/Start-Up
  - Inoculum: perc1ace (Herman and Frankenberger, 1999)
  - Batches of this isolate were grown in flasks containing Celite minimal salts medium supplemented with ClO_4^- (500 mg L^{-1}) and acetate (1 g L^{-1})
  - Batches were poured into and circulated through the column for two weeks

Methodology (Continued)

- Operation/analytical
  - Influent feeds were introduced in an up-flow mode

TDS and ClO_4^- Concentration of Influent Feeds (mg L^{-1})					
Groundwater		**RO**		**RO2**	
320	0.8	2025	5	4050	8

  - Acetate (sodium acetate), 500 mg L^{-1}
  - Ammonium and phosphate (NH_4Cl and KH_2PO_4)
  - Each test lasted approximately 4 weeks
  - ClO_4^-, NO_3^-, SO_4^{2-} analyzed periodically using IC (DL = 0.004 mg L^{-1}; 0.2 mg L^{-1}, respectively)

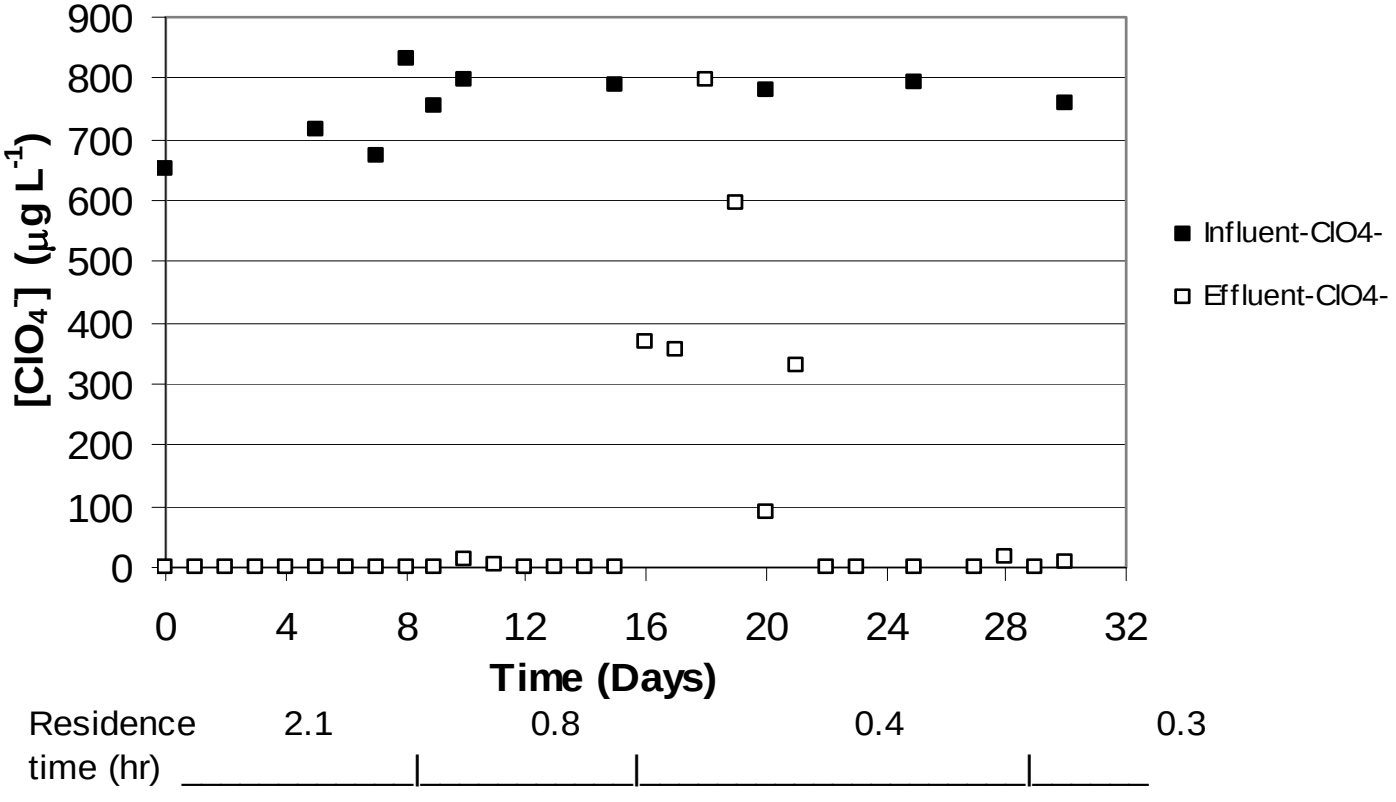
Methodology (Continued)

- General Approach
  - Begin with a residence time that yielded non-detectable effluent ClO_4^- concentrations
  - Incrementally increase the flow rate, thereby decreasing the residence time, until ClO_4^- breakthrough occurred

Flow Rate (mL min^{-1})	Residence Time (hours)
5	4.2
10	2.1
25	0.8
50	0.4
75	0.3

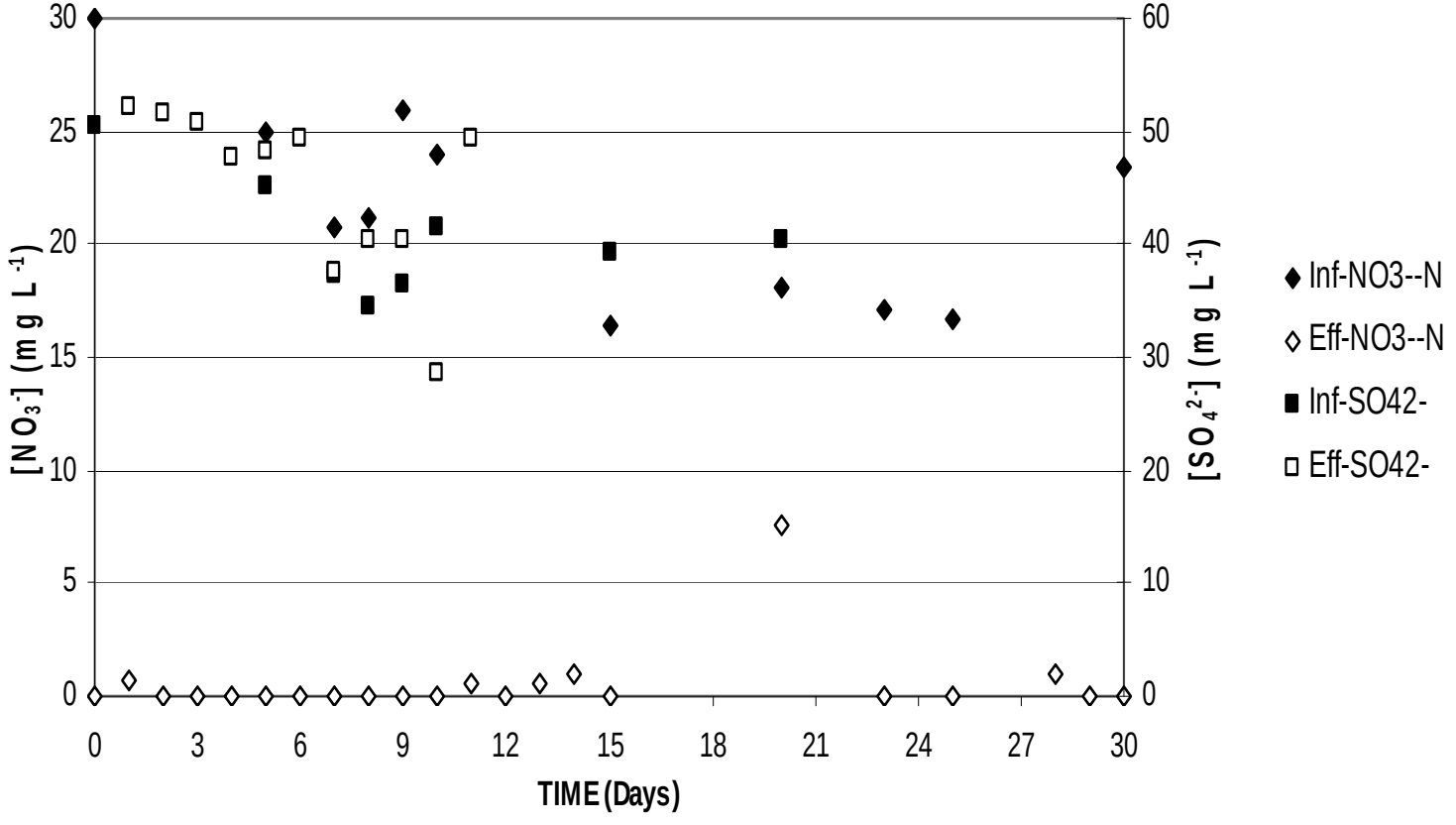
Results and Discussion

- Test 1: Treatment of Groundwater
  - Influent and effluent [ClO_4^-] vs. time



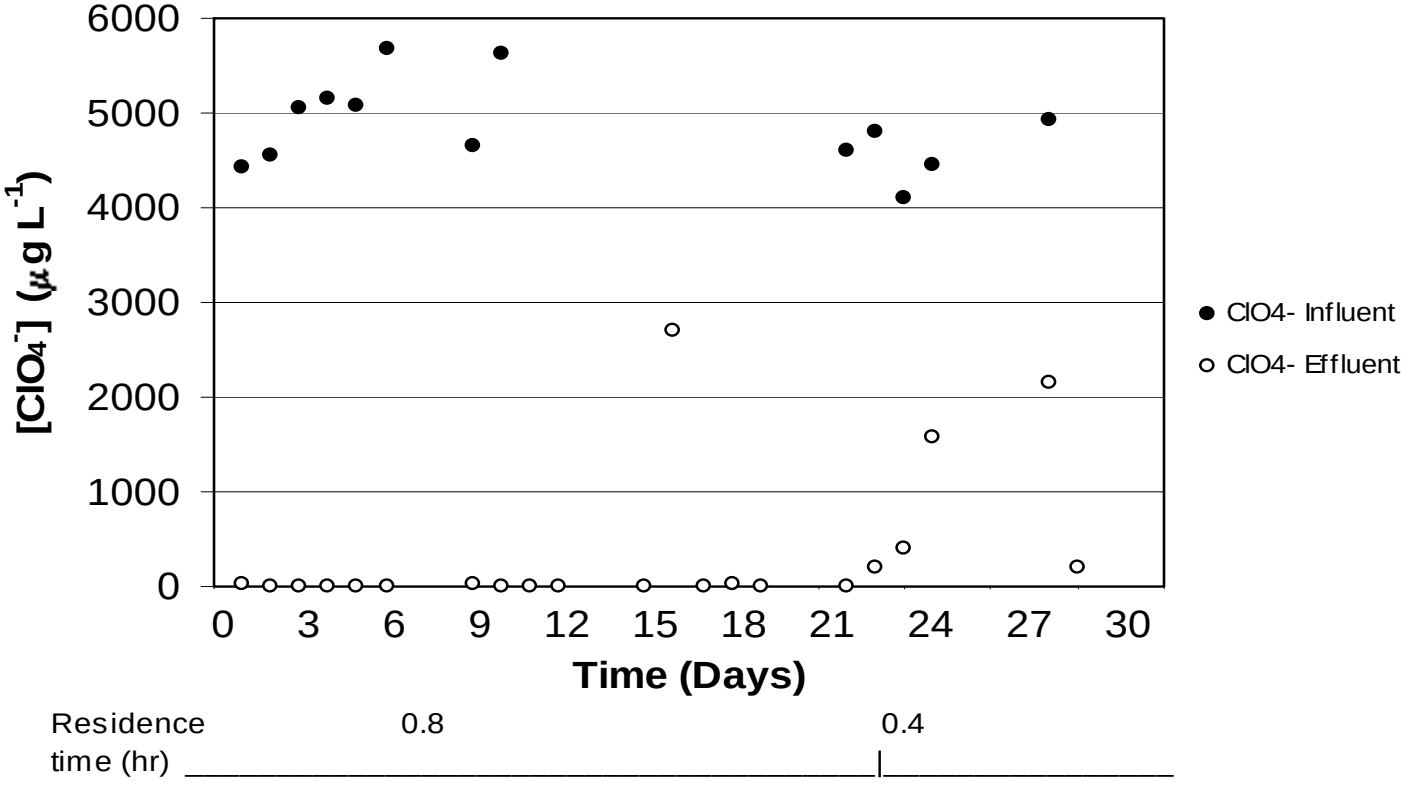
Results and Discussion (Continued)

- Test 1: Treatment of Groundwater
  - Influent and effluent $[NO_3^-]$ and $[SO_4^{2-}]$ vs. time



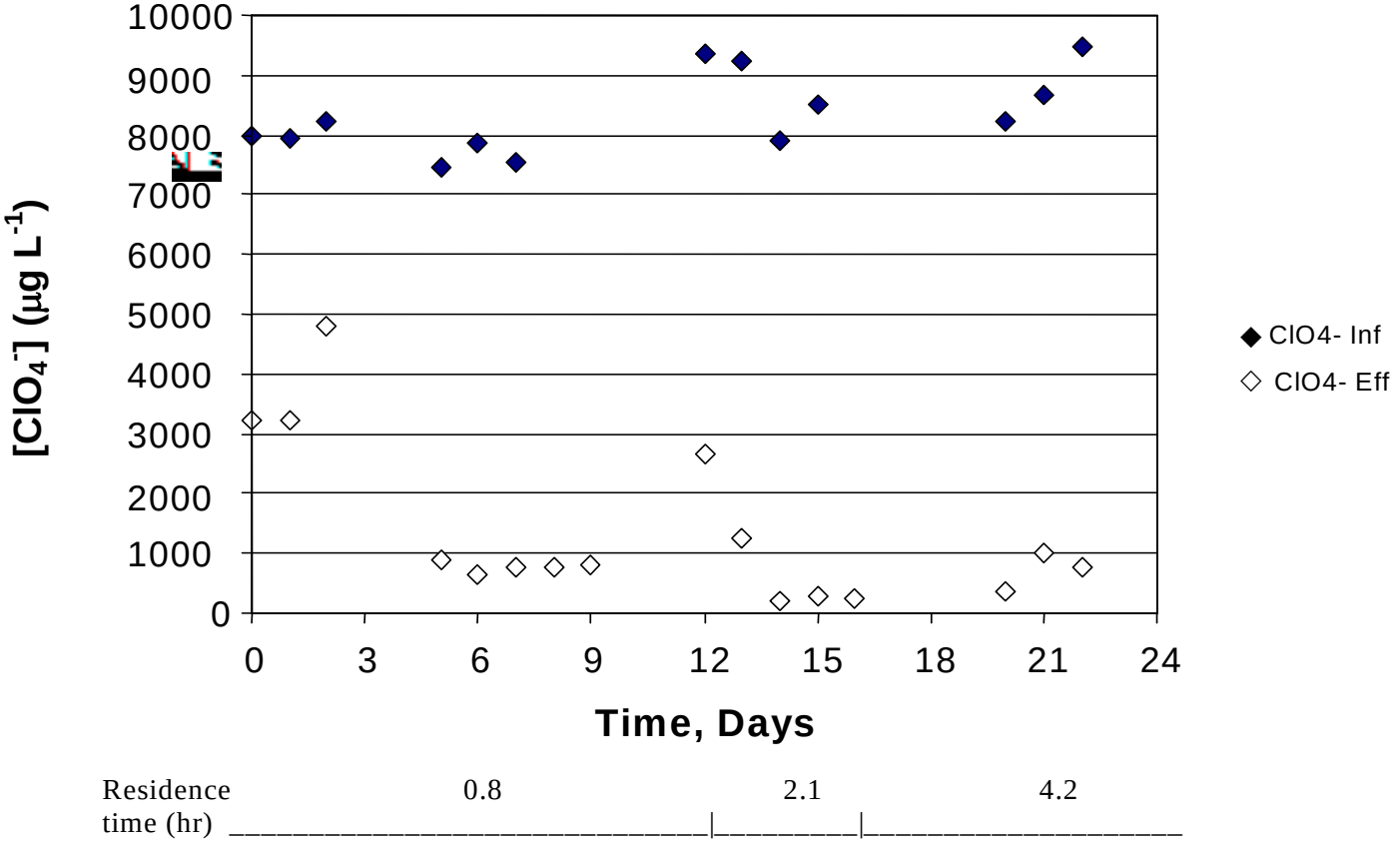
Results and Discussion (Continued)

- Test 2: Treatment of Primary RO Rejectate
  - Influent and effluent [ClO_4^-] vs. time



Results and Discussion (Continued)

- Test 3: Treatment of Secondary Rejectate
  - Influent and effluent [ClO_4^-] vs. time



Summary/Conclusions

- PBR/Perc1ace System
  - Groundwater
    - ~0.8 mg ClO_4^- L^{-1} => ND (<0.004 mg ClO_4^- L^{-1})
      Residence time: 0.3 hr
  - Primary RO Rejectate
    - ~5.0 mg ClO_4^- L^{-1} => ND (<0.004 mg ClO_4^- L^{-1})
      Residence time: 0.8 hr
  - Secondary RO Rejectate
    - ~10 mg ClO_4^- L^{-1} => 0.2 mg ClO_4^- L^{-1}
      Residence time: 2.1 hr
  - Significant removal of NO_3^- from all three feeds noted
  - Sulfate reduction not observed

Acknowledgement

The authors recognize and thank Ed Coppola of Applied Research Associates for his work in calculating salt additions to match target concentrations for the RO rejectates.