Pilot-scale Tests of Fixed Bed Reactors for Perchlorate Degradation: Plastic Medium Bioreactors

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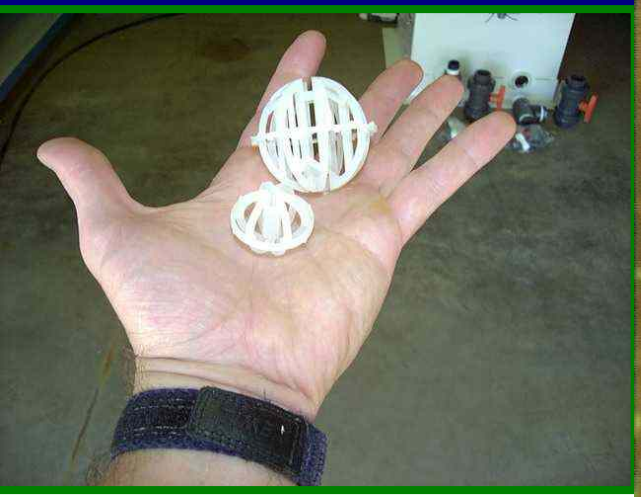
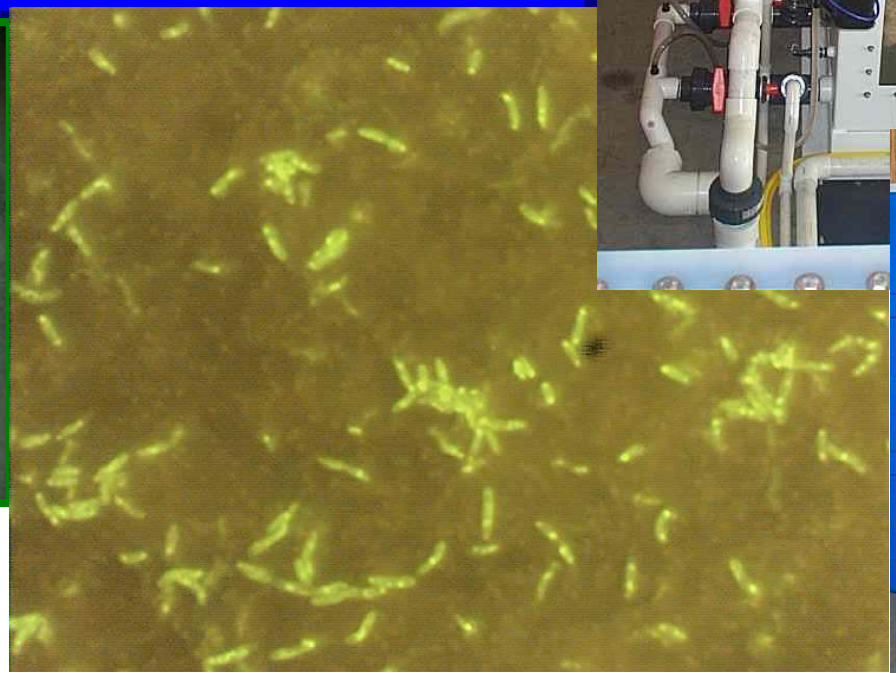
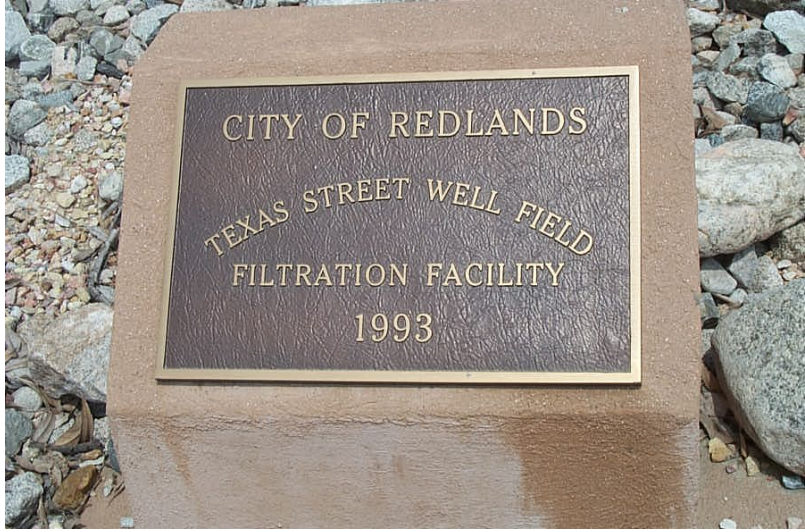




Study Participants

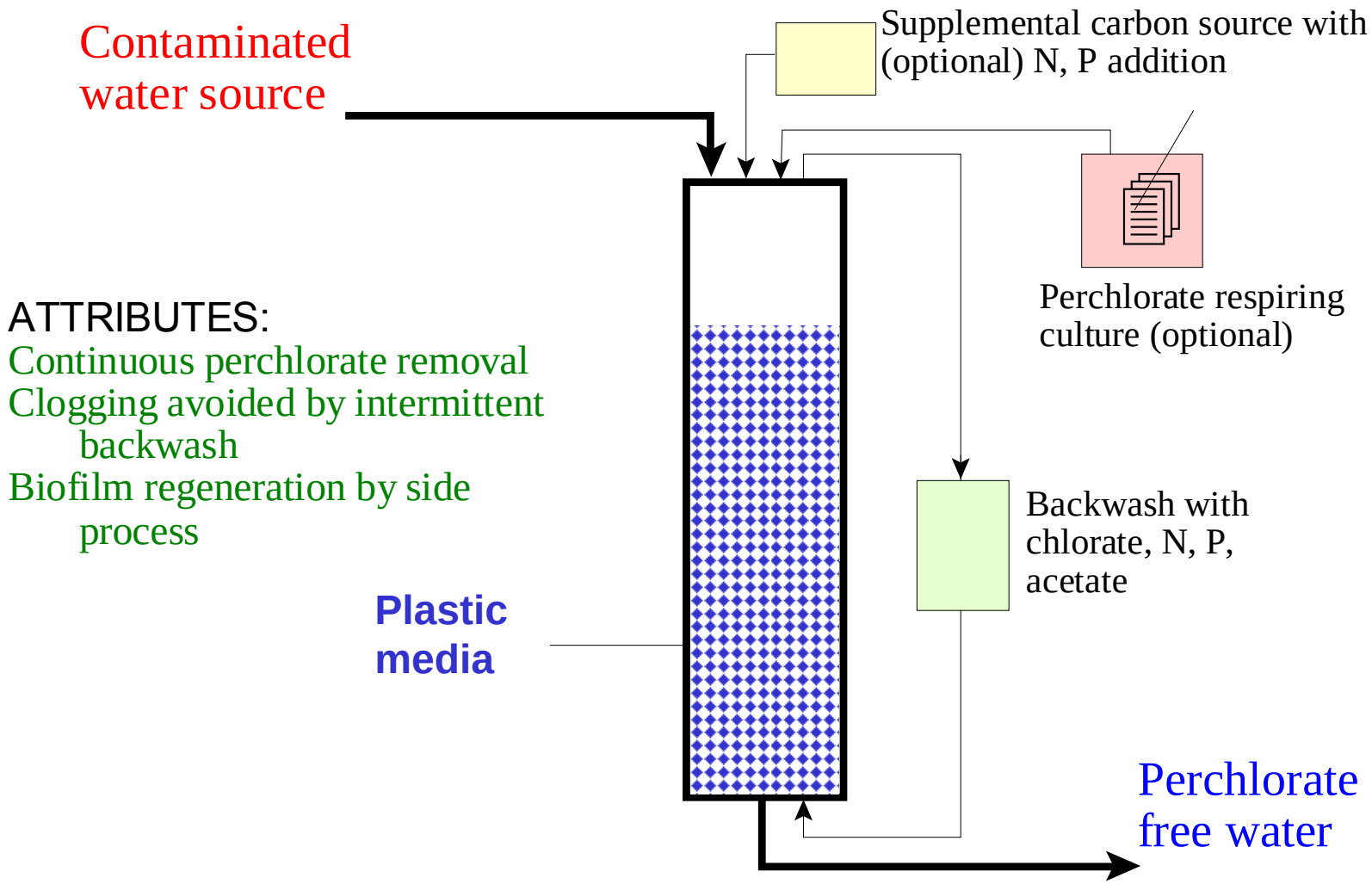


- Site: Redlands, California, Texas St well field
- Engineering Firm: Camp, Dresser and McKee, Inc.
- Research Unit: The Pennsylvania State University
- Funding Agency: American Water Works Association Research Foundation (AWWARF; via an EPA Grant)

Plastic Medium Bioreactor

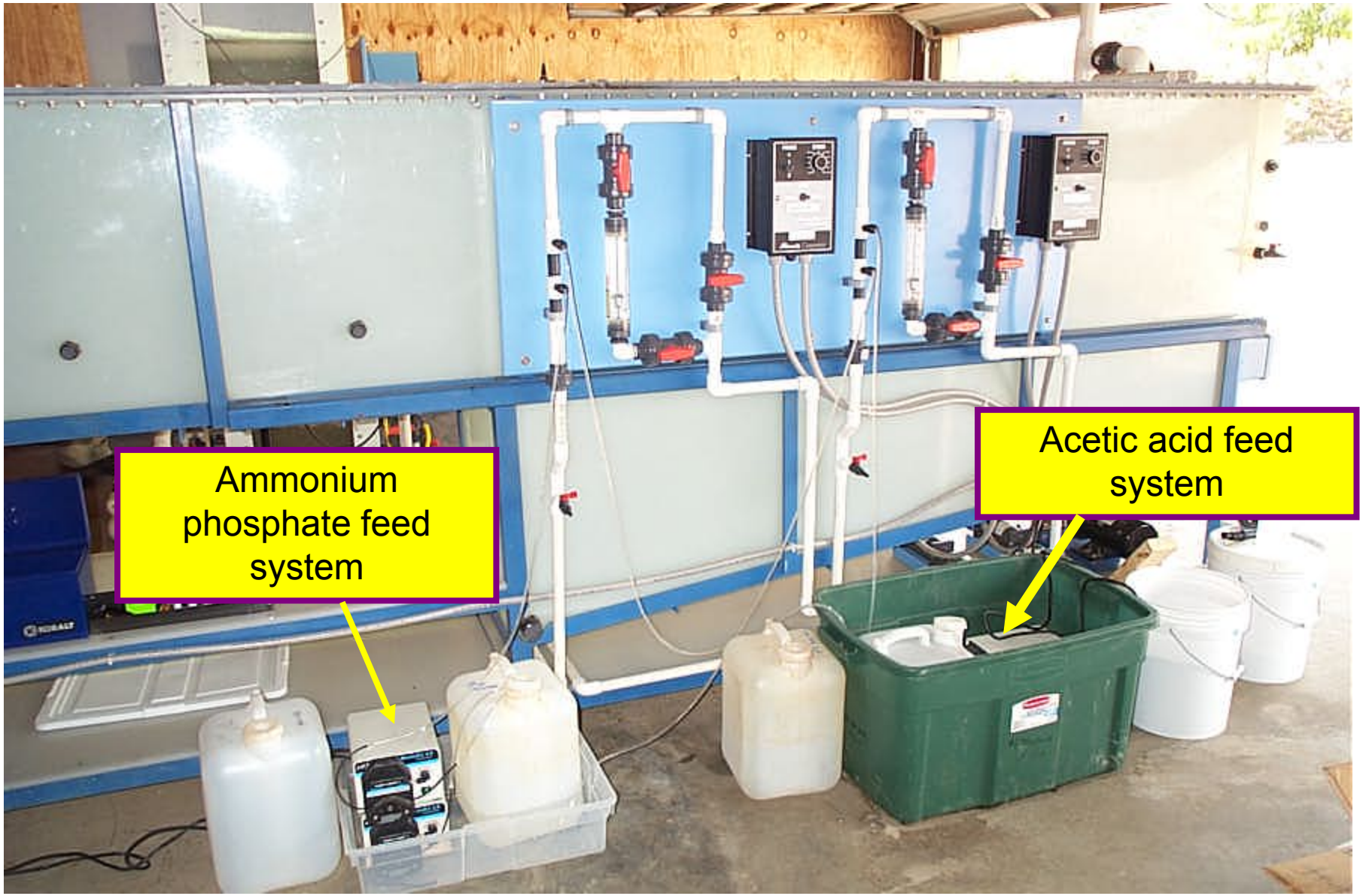
- System configuration
- Performance during six-month field tests in Redlands CA
- Reactor scale up- effect of dispersion in a packed bed reactor
- Reactor performance compared with other studies
- Stability of the bacterium used for inoculation

PSU-O4 Process Patent: Perchlorate degradation in a fixed bed bioreactor (U.S. Pat. No. 6214607)

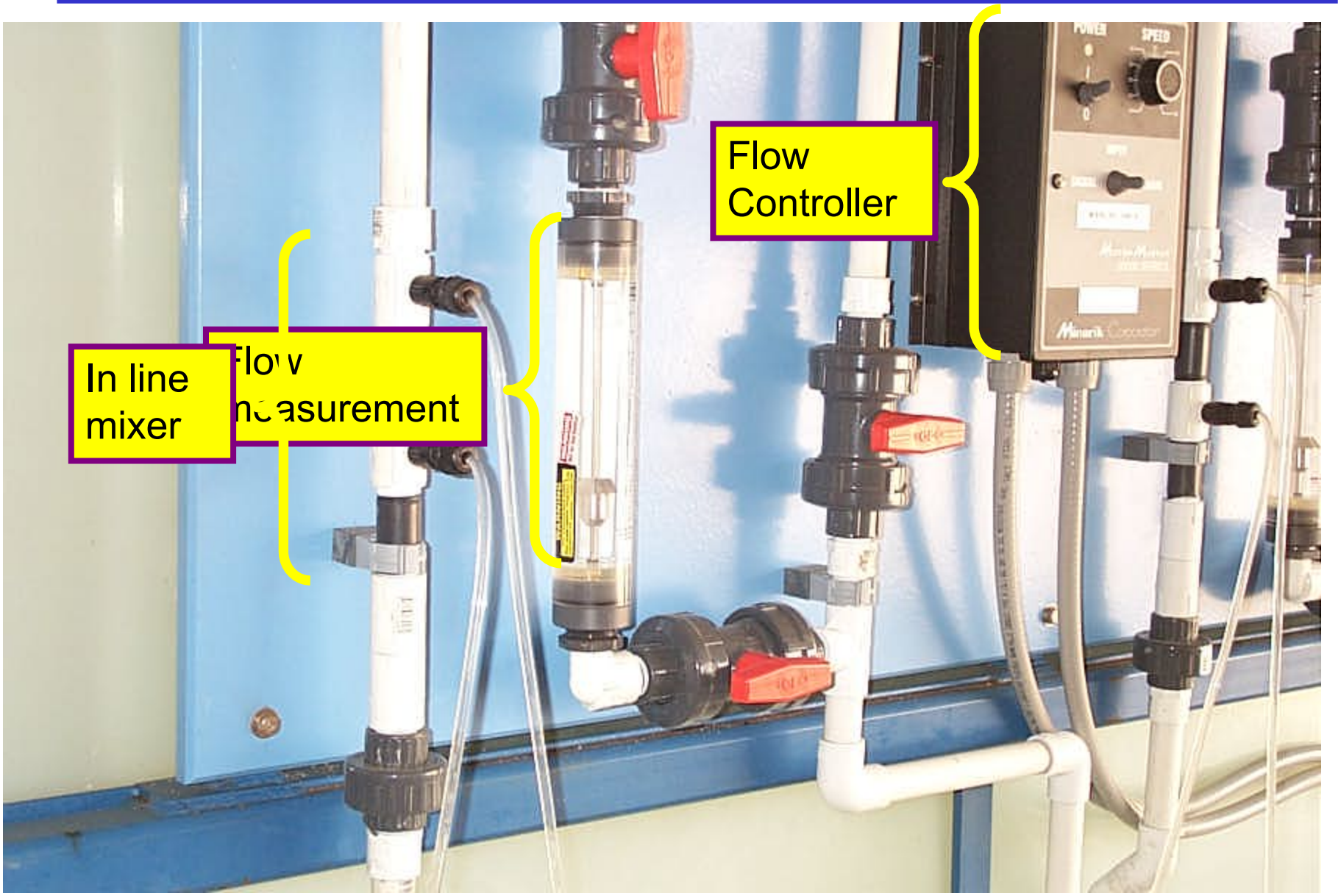


Penn State University

Filter inlet controls mounted in storage tank



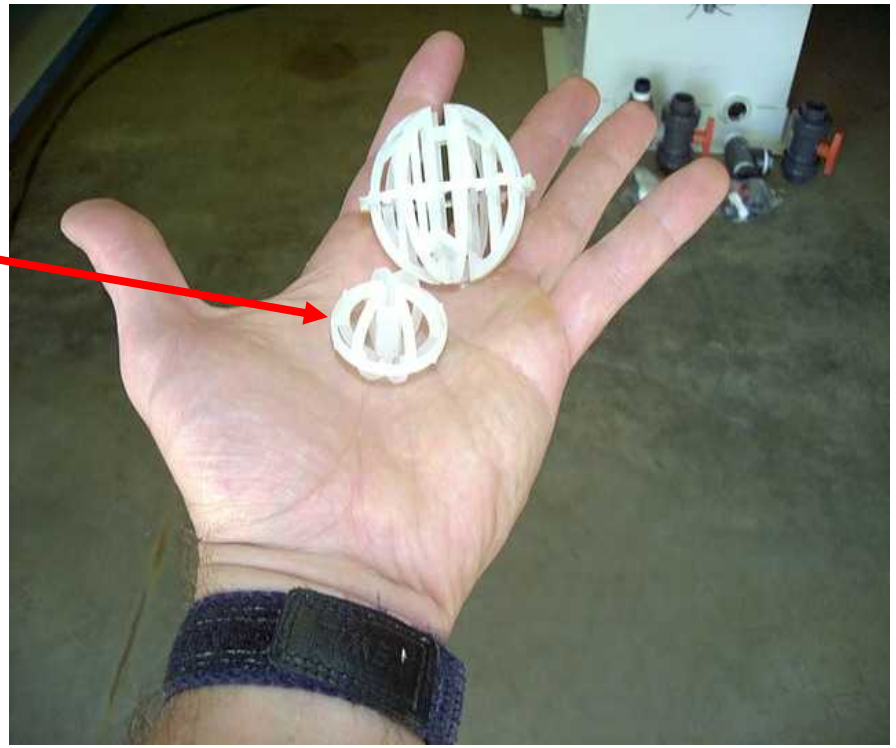
In line mixers, flow measurement, and flow controller



Plastic Media used in Reactor

Tri-Pack Plastic Media

(3.175 cm diameter)



Plastic medium bioreactor

Media is held in place by a perforated metal plate

Media floats in water, producing entrance region

Plastic medium bioreactor

During backwashing, media falls down, creating a mixing zone

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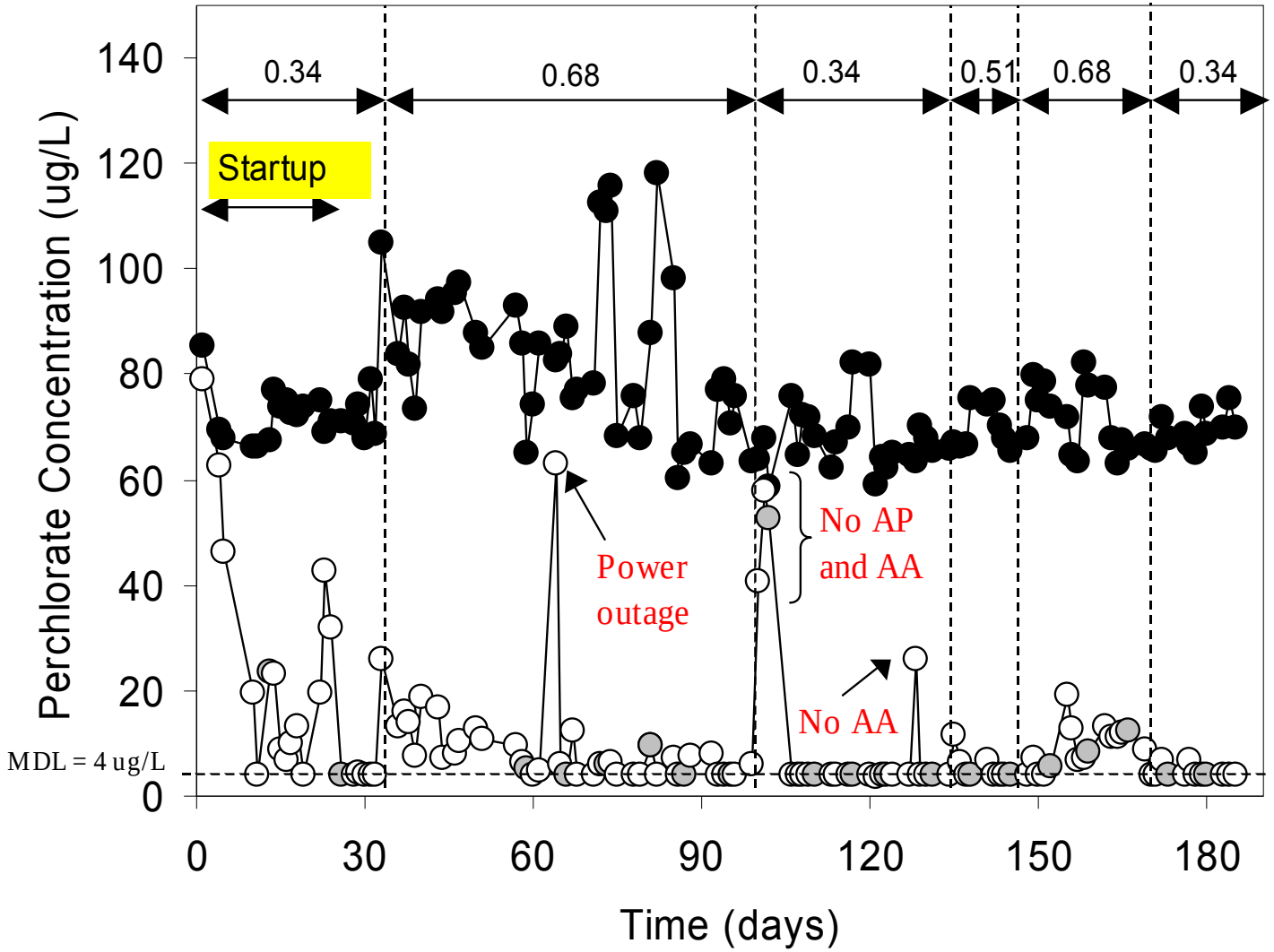
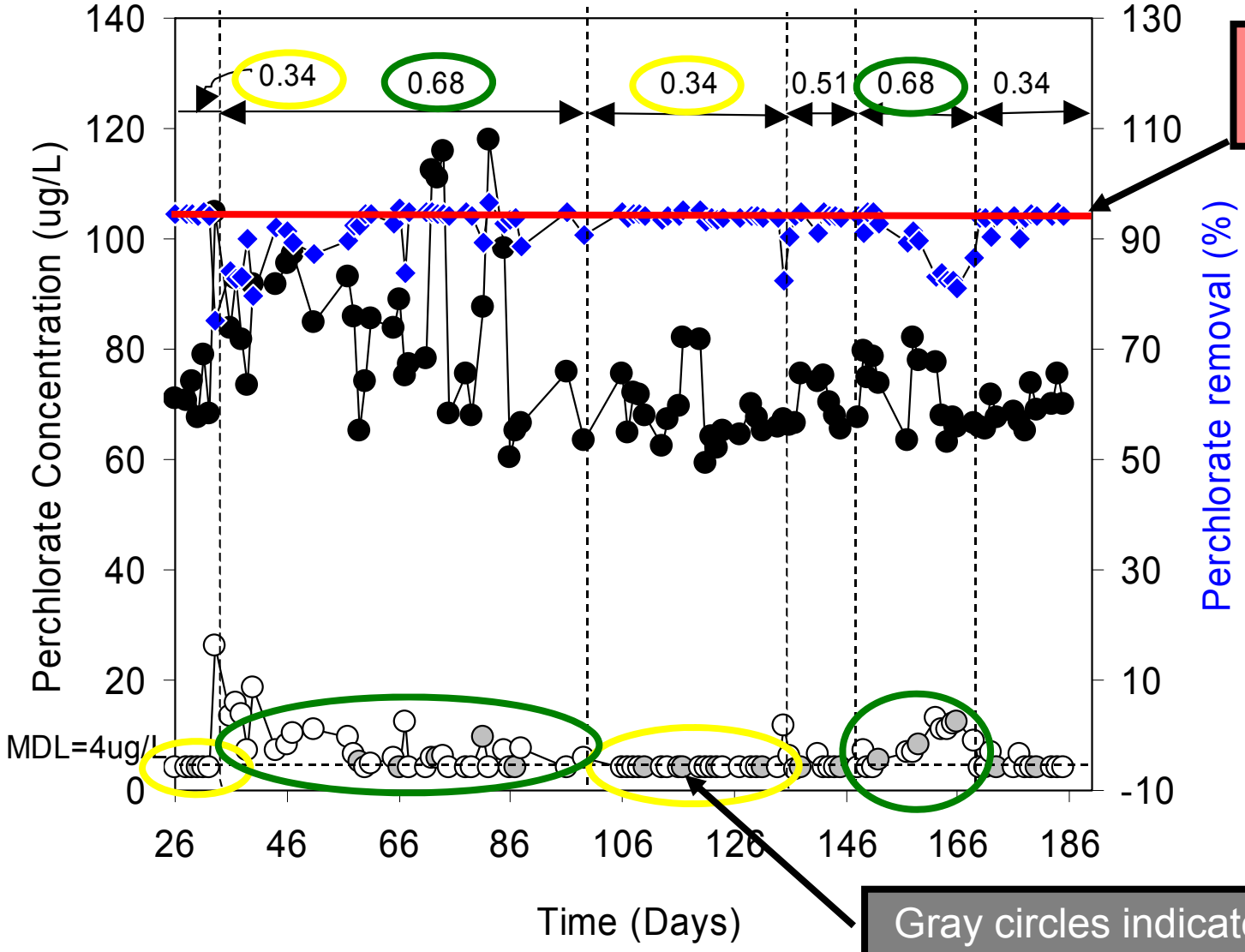
Groundwater Characteristics

Parameter	Value	Units
Perchlorate	50 – 120	ug/L
Nitrate	4 - 4.5	mg/L-N
Oxygen	8 – 10	mg/L
TCE	3 – 5	ug/L
1,1-DCE	1 – 2	ug/L

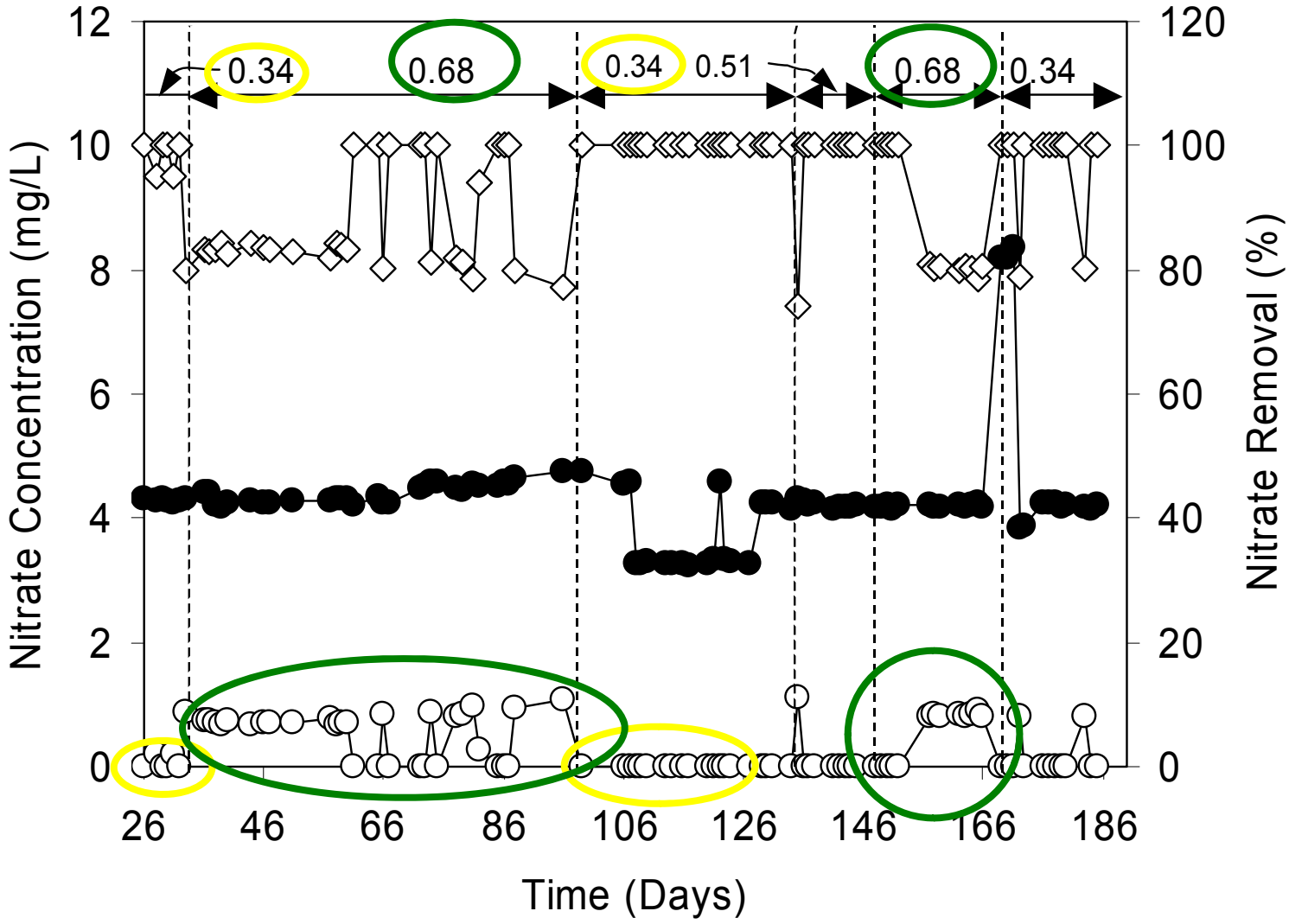
Perchlorate Removal: All Data



Perchlorate removal: Proper operation

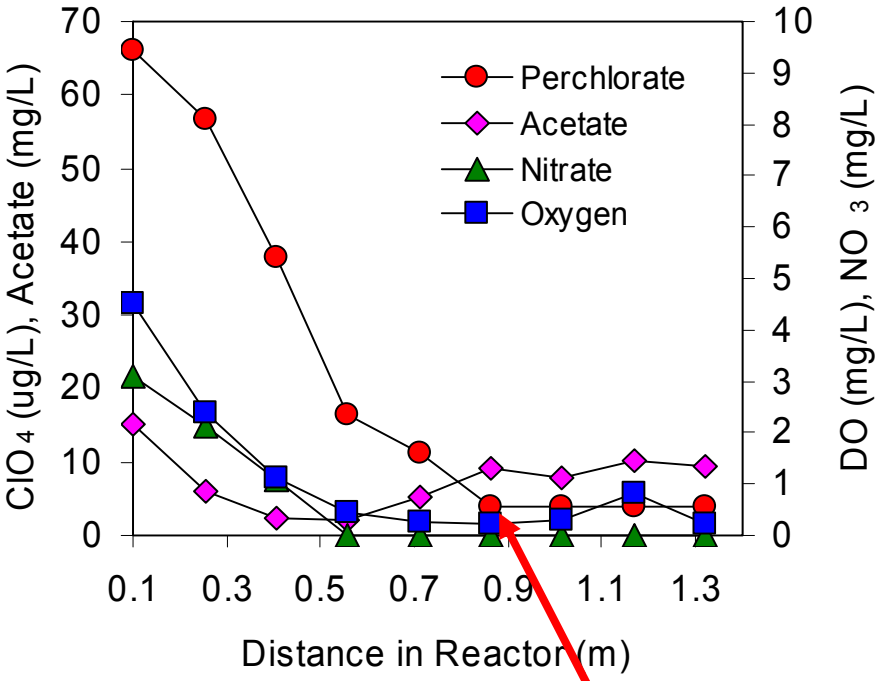


Nitrate Removal

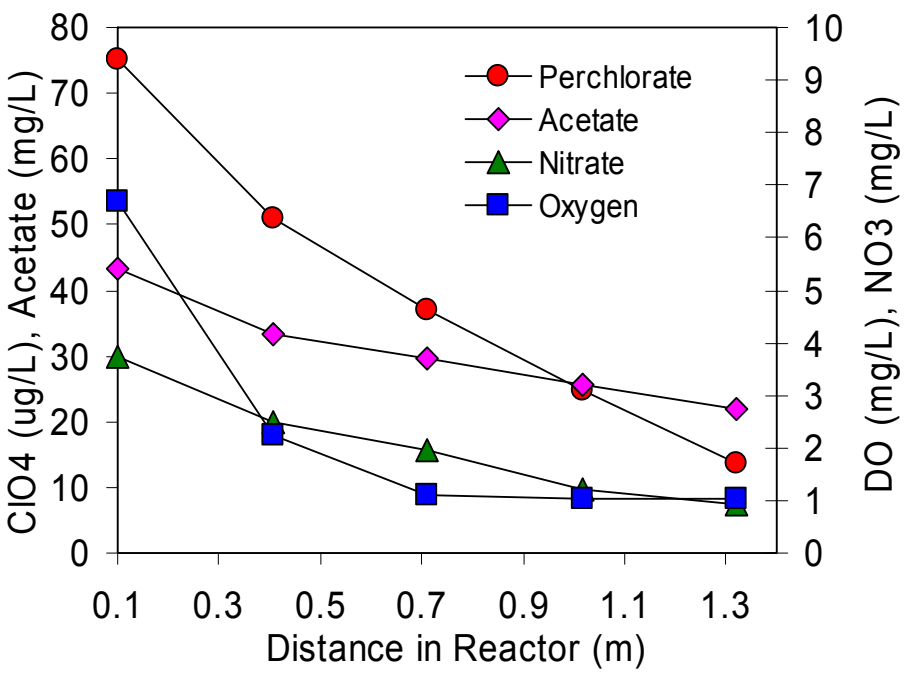


Chemical Profiles in Reactor

0.34 L/m²s (day 127)



0.68 L/m²s (day 162)

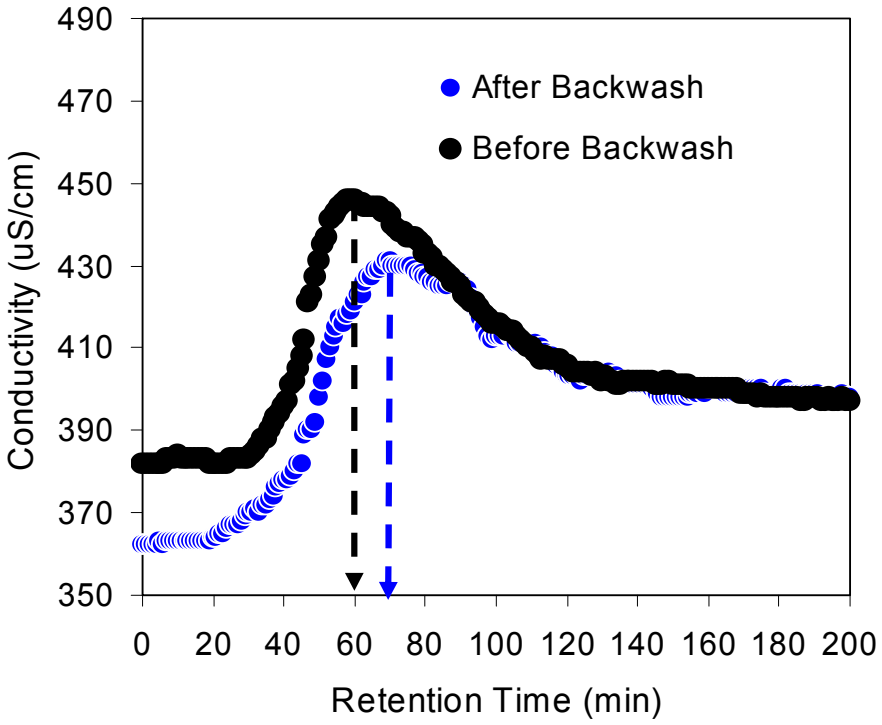


Perchlorate removed by 0.9 m

(slightly over half way in the reactor)

Detention Time Measurements

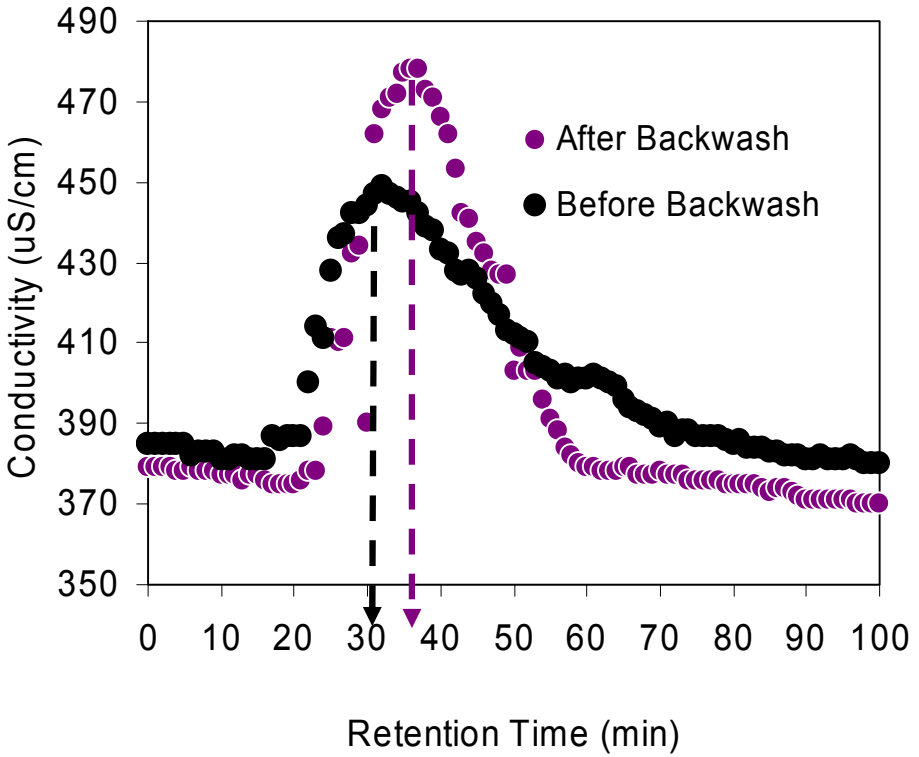
0.34 L/m^{2}s (day 172)



Before backwash: 60 min

After backwash: 70 min

0.68 L/m^{2}s (day 166)



Before backwash: 32 min

After backwash: 37 min

Acetic acid and Nutrients

Measurements	Influent	Effluent
Acetic acid (mg/L)	51 ±9	21 ±8
pH	6.72 ±0.12	6.80 ±0.19
Phosphate (mg/L)	12.8 ±3.6	12.1 ±2.6
DOC (mg/L)- g.w.	0.28	----
- reactor	18 ±5	8.3 ±5.6
Turbidity (NTU)	----	3.39 ± 3.75

Summary of Other Water Parameters

Measurements	Influent	Effluent
Temperature (ºC)	19.7 ±0.7	19.4 ±0.7
Conductivity (µS/cm)	394 ±9	378 ±36
Dissolved Oxygen (mg/L)	8.7 ±0.4	0.2 ±0.3
ORP (mV)	8 ±52	-85 ±77
Sulfate	33 ±2	----
1,1-Dichloroethene (µg/L)	1.2 ±0.2*	1.3 ±0.2
Trichloroethene (µg/L)	3.7 ±0.5*	3.5 ±0.6

* Groundwater prior to amendments (data after day 26).

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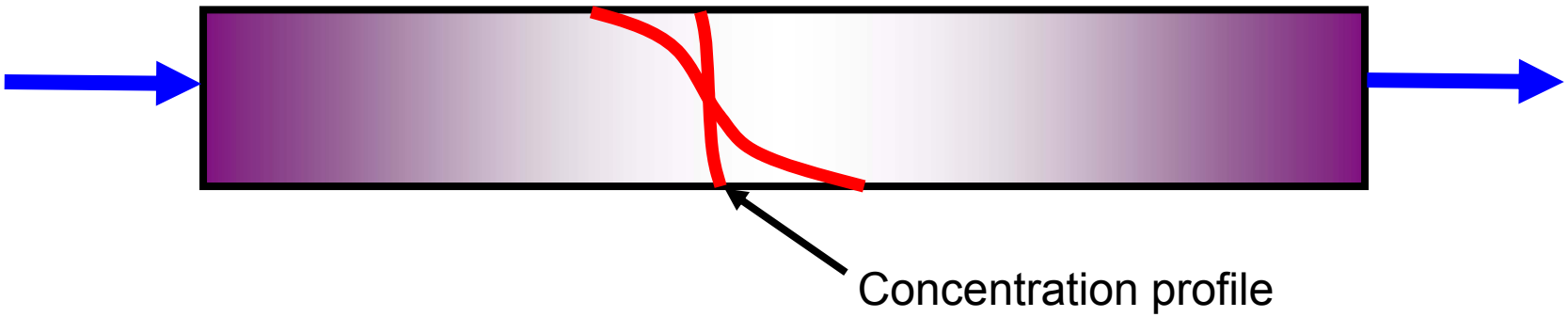
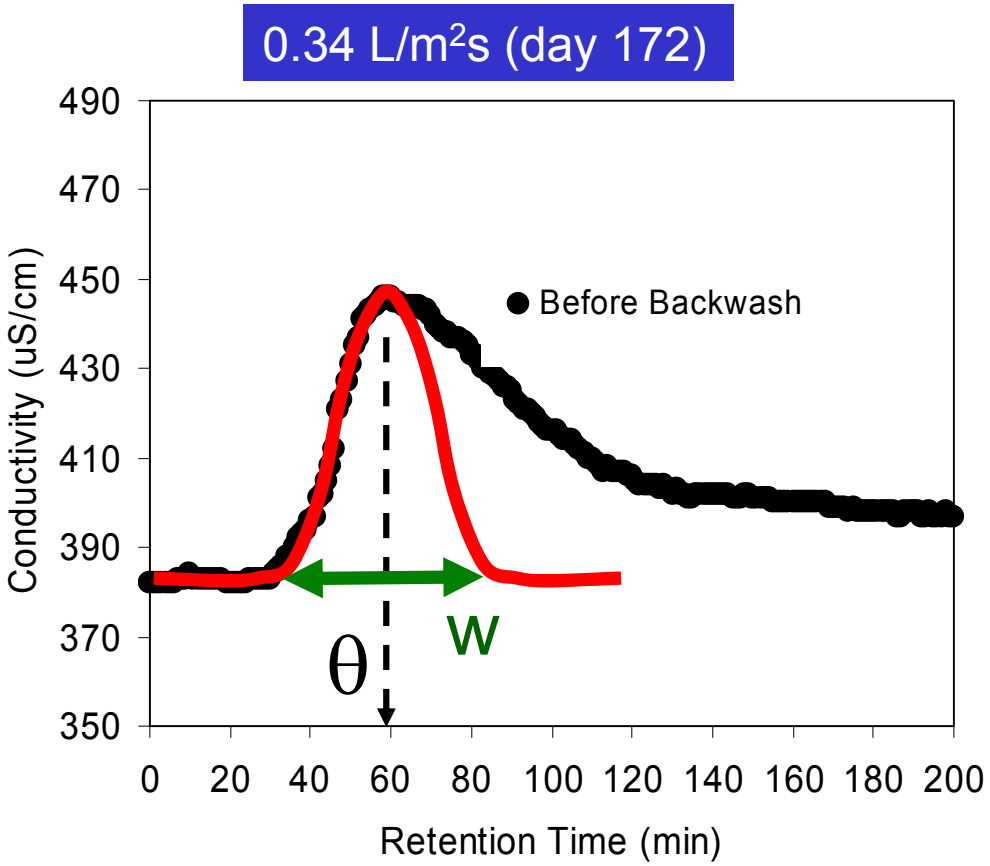
Effect of Dispersion on Performance



- Dispersion results in some fraction of the material to be in the reactor less time: result is less treatment
- Importance of dispersion can be evaluated from the magnitude of the Peclet number (Pe)
- To calculate Pe, need to measure dispersion coefficient (E).

E can be calculated from detention time (θ) measurements



The Dispersion coefficient is calculated as:

$$w = 6(2E\theta)^{1/2}$$

The Peclet number is calculated as:

$$Pe = \frac{uL}{\theta}$$

u= water velocity

L= length of column

Results of Peclet Number Calculations

- Dispersion is important when Pe<5.
- In plastic medium reactor, Pe ranged from 16 to 44.
- In sand reactor, Pe ranged from 22 to 140.
- Based on these results, dispersion was not important for overall rate of reaction (only critical factor was detention time).

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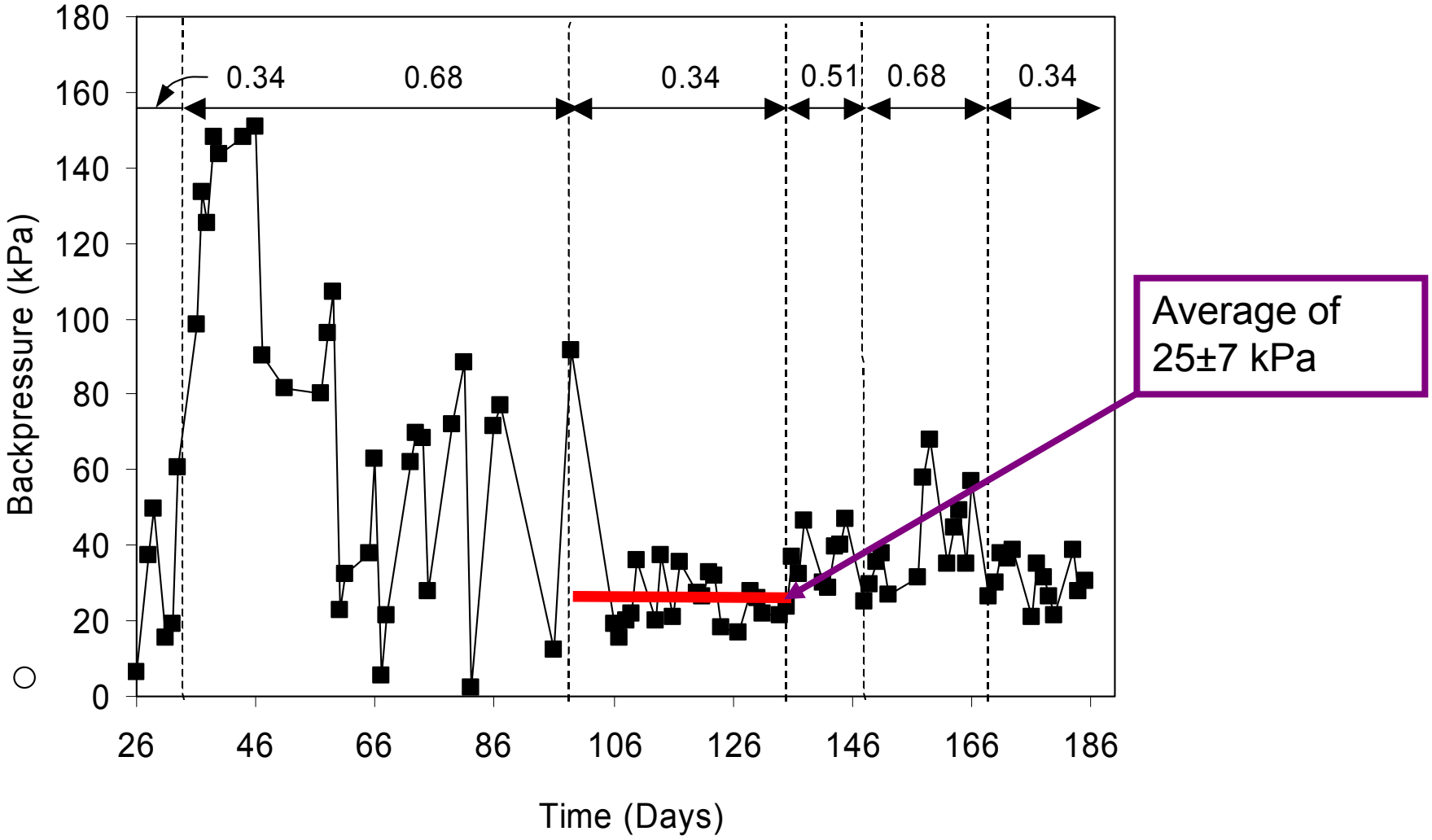
Which Fixed Bed Reactor is Better?

Sand media reactor

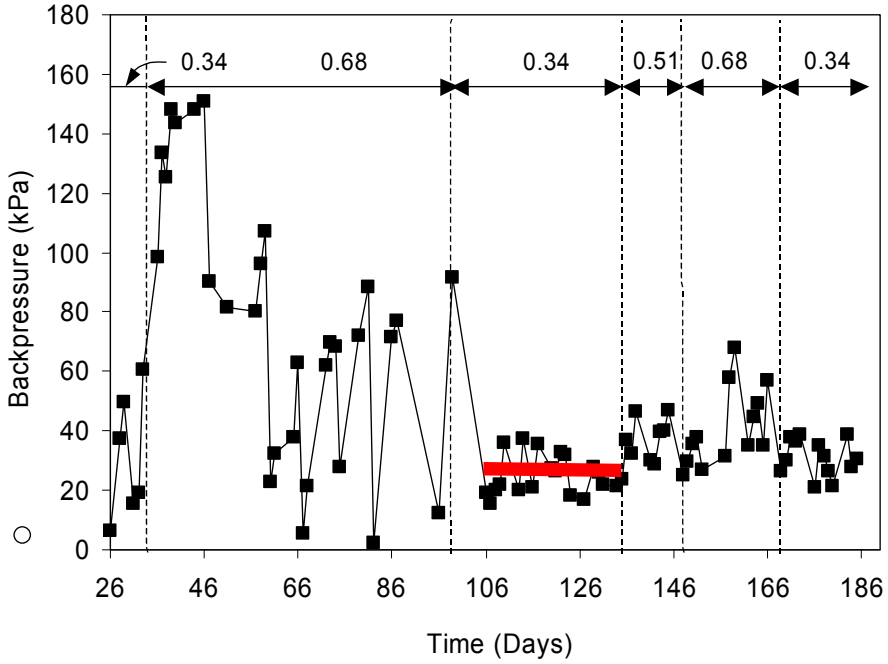
Plastic media reactor

Backpressure measurements



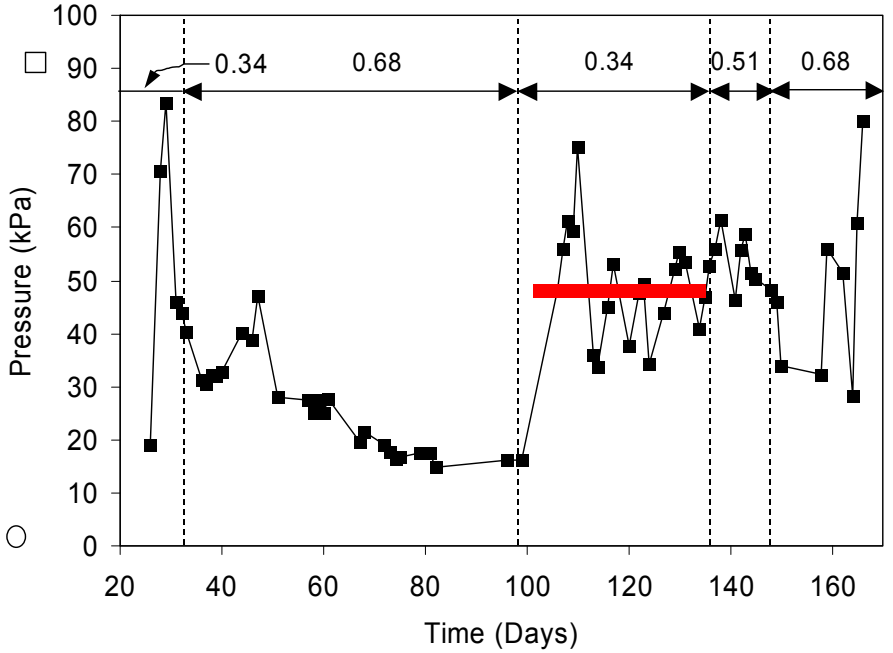
Backpressure: Plastic vs Sand

Plastic media



Average of 25±7 kPa

Sand media



Average of 50±11 kPa

Reactor Kinetics: Removal Rates

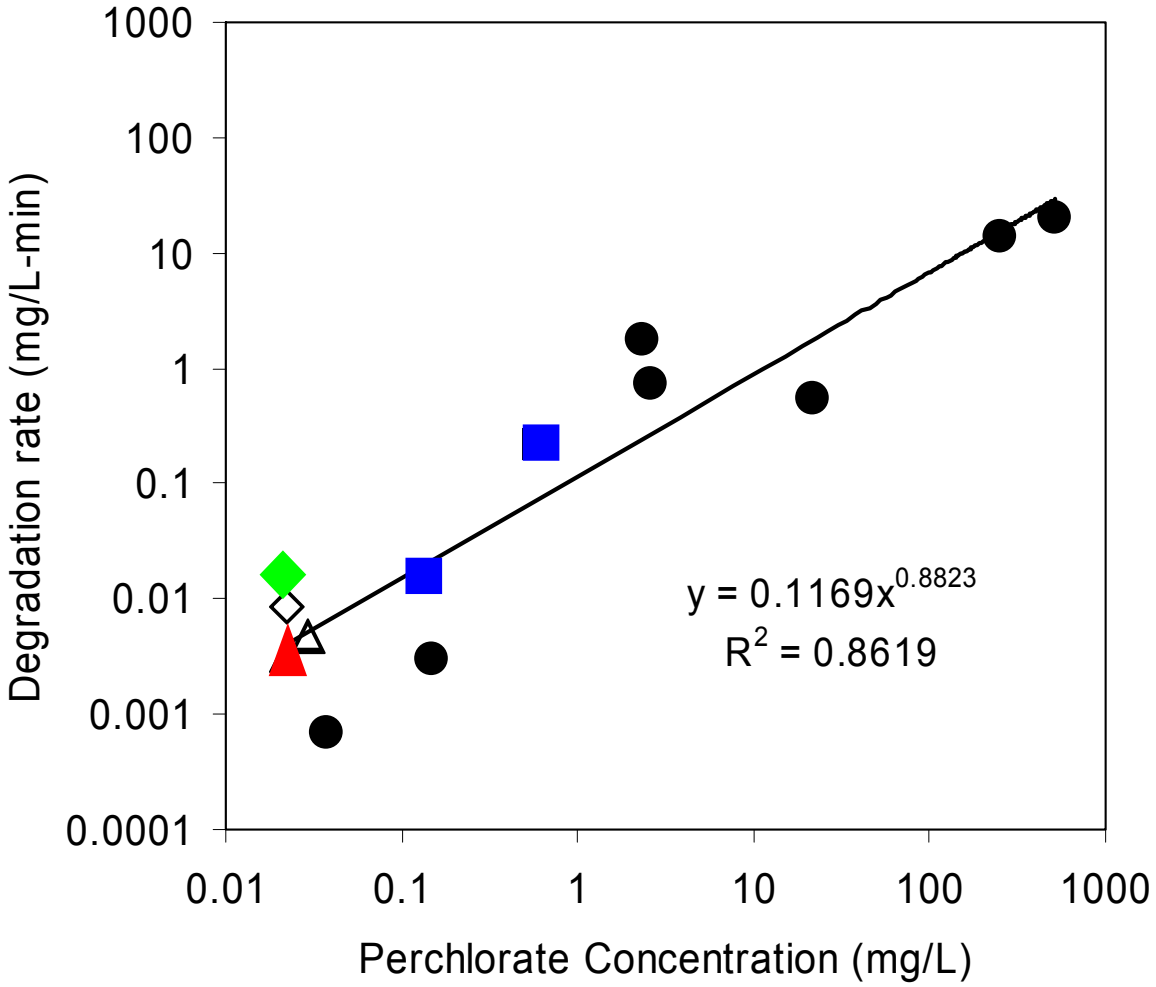
- Expect removal rate, R, is 1st-order with respect to perchlorate concentration.
- Rate calculated as:

$$R = \frac{(Cin - Cout)}{\theta}$$

- For 1st-order kinetics, use log mean perchlorate concentration

$$C_{lm} = \frac{C_{in} - C_{out}}{\ln (C_{in} / C_{out})}$$

Rates in Plastic and Sand Medium Reactors vs Other studies



Plastic media (0.34 L/m²s)

Sand media (0.34 L/m²s)

Inorganic substrate

Other organic substrates

Recommendation: Plastic Media

- Plastic media has lower back pressure, and therefore lower operation costs
- Plastic media easier to backwash than sand media
- No loss of plastic media from reactor during backwashing
- Sand media has greater removal rate on a reactor-volume basis
- Given the above considerations, the plastic media is recommended for biological perchlorate degradation.

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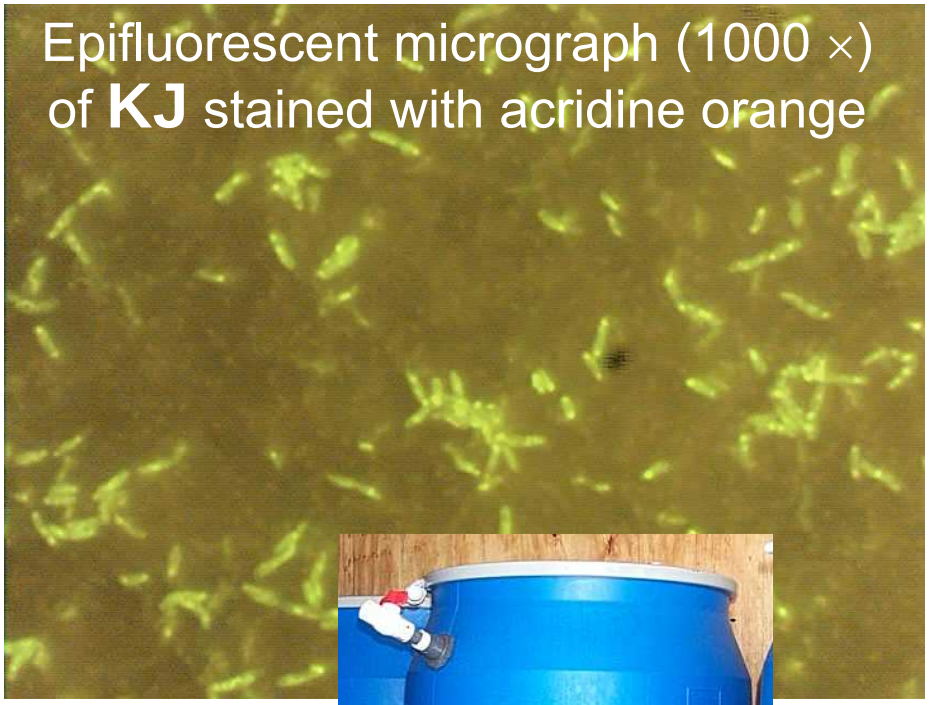
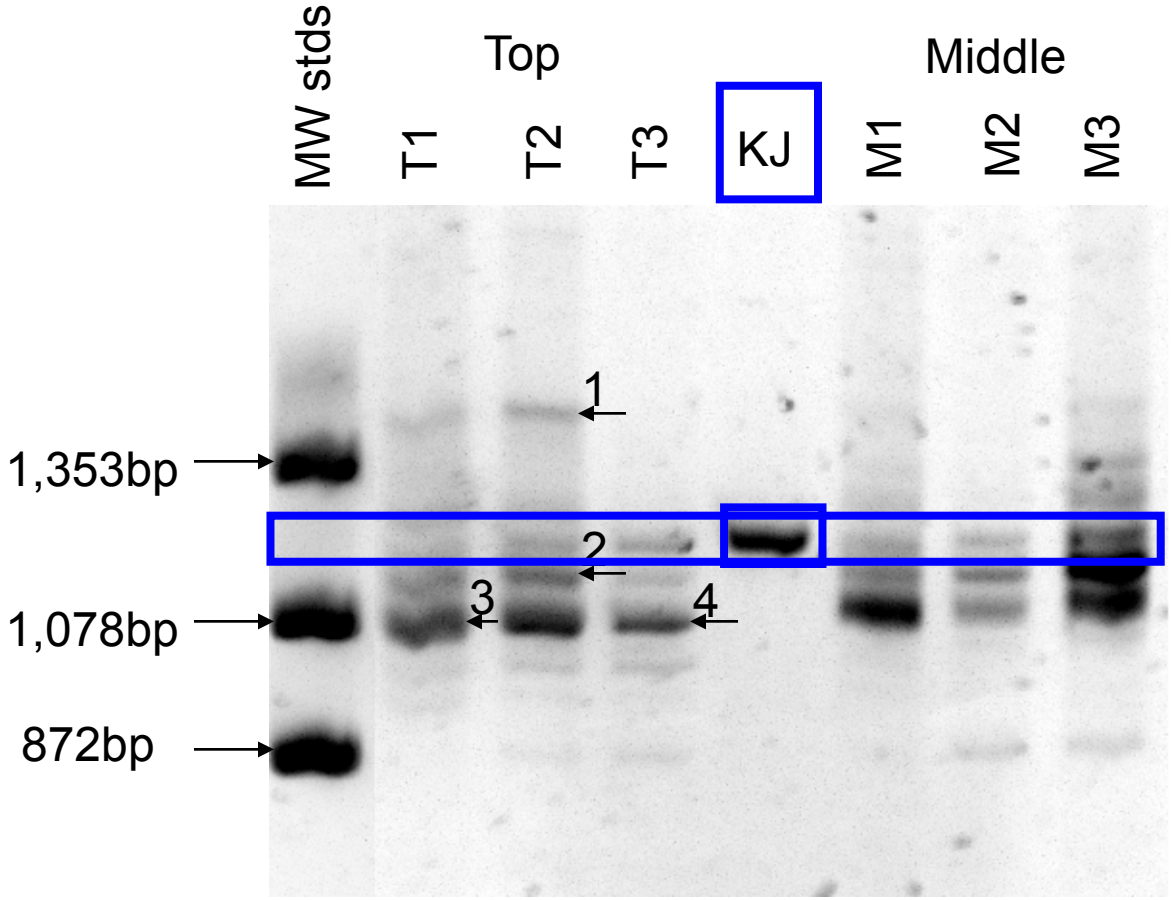
Did *Dechlorosoma* sp. KJ survive?

- Reactor inoculated with a pure culture
- Other bacteria present in groundwater
- Sterile conditions not maintained
- Electron acceptors present in order: oxygen>nitrate>> perchlorate



Perchlorate reducing microbial community profile (Preliminary Results)



What are the other prominent members of the microbial community?

1: uncultured *Bacteroidetes*

2: uncultured *bacteria*

3, 4: *Dechloromonas* sp. strain HZ

Implications of community shift

- Isolate KJ removed perchlorate more efficiently than mixed cultures in laboratory studies
- Laboratory reactor with KJ had a minimum detention time of ~2 minutes (sand)
- Mixed culture required ~10 minutes in the laboratory for complete perchlorate removal
- Found in pilot-scale sand reactor a minimum detention time of ~10 minutes
- Community profiling indicates reactor became a mixed culture. This explains why 10 minutes was necessary for reactor design.

CONCLUSIONS

- Perchlorate (and nitrate) were completely removed in a plastic medium bioreactor at a hydraulic loading rate of 0.34 L/m^2-s (0.5 gpm/ft^2)
- Backwashing once a week was needed to prevent excessive biofilm buildup
- Perchlorate was removed at the same time as nitrate
- Community analysis indicates that the inoculated microbe was only a part of a diverse biofilm community that developed in the reactor.

ACKNOWLEDGMENTS

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Camp, Dresser & McKee, Inc.	Pat Evans, Allyson Chu, Steven Price, Stephen Liao, Harold Pepple, Dick Corneille, Mike Zaefer
Students	Booki Min, Yanguang Song, Husen Zhang,
Funding	AWWARF: Project manager Frank Blaha

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Min, B., P. Evans, A. Chu, and B.E. Logan. Perchlorate removal in a pilot plant-scale packed bed bioreactor- 2: Plastic medium bioreactor. *Submitted.*