CMP Waste Treatment with a Forced-Flow Electrophoresis Device

(Subtask A-4-1)

Jamie L. Ludke

Milan Bier

James C. Baygents

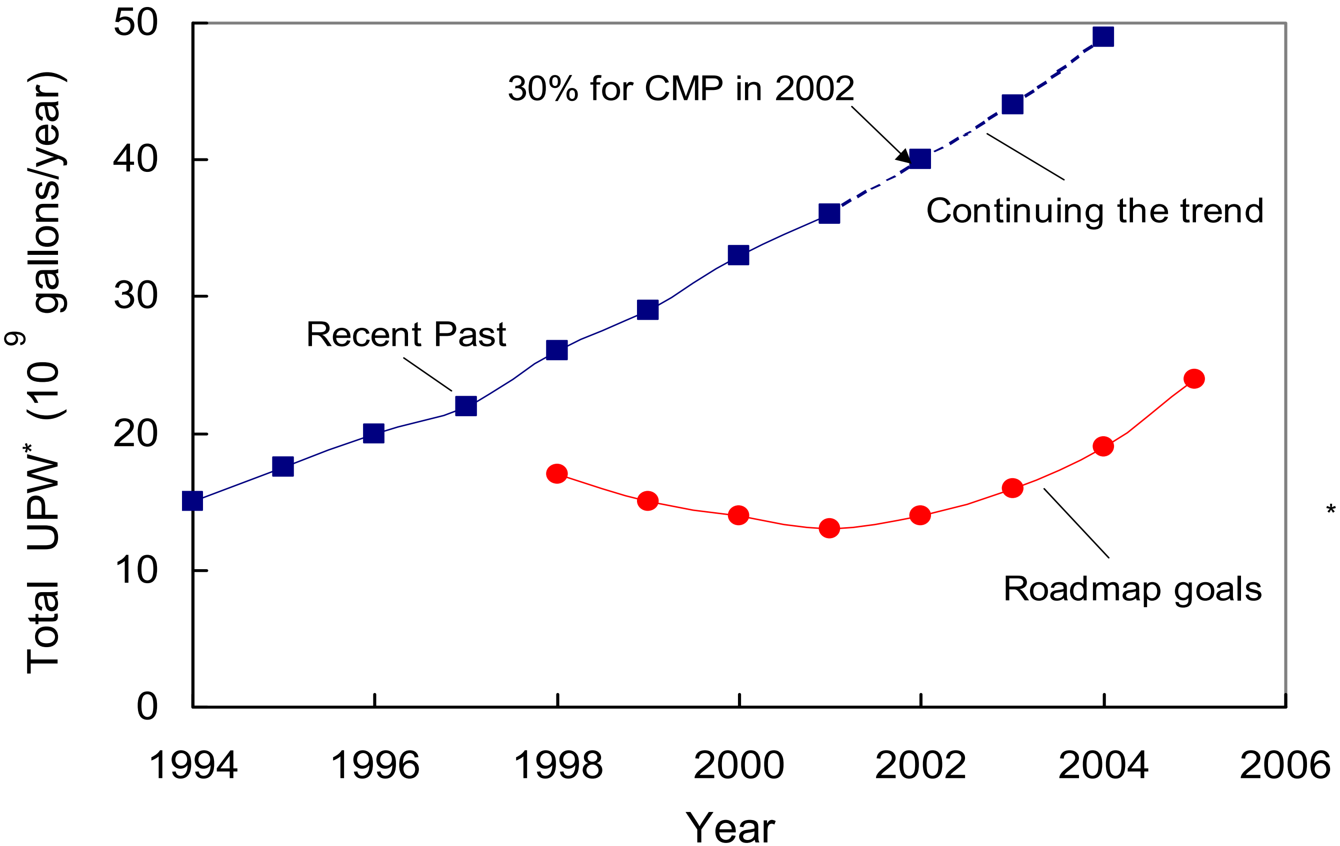
The University of Arizona

Outline

- Motivation
- Description of Forced-Flow Electrophoresis
- Results
- Additional Research
- Potential Transfer of Technology
- Concluding Remarks

ITRS Technology Barrier: Sustainability vs. Resource Consumption

In 2002 CMP will constitute approximately 30% of UPW usage.
UPW consumption continues to exceed Roadmap goals.



* UPW Data:
Sematech Survey,
NTRS Roadmap and
Estimates (F. Shadman).

ITRS Technology Barrier: Sustainability vs. Resource Consumption (cont.)

Current Trend†

- One CMP tool requires:
  - 7,000 gallons of UPW per day
  - 12,000 gallons feed water per day
- As device linewidths shrink additional CMP will be required

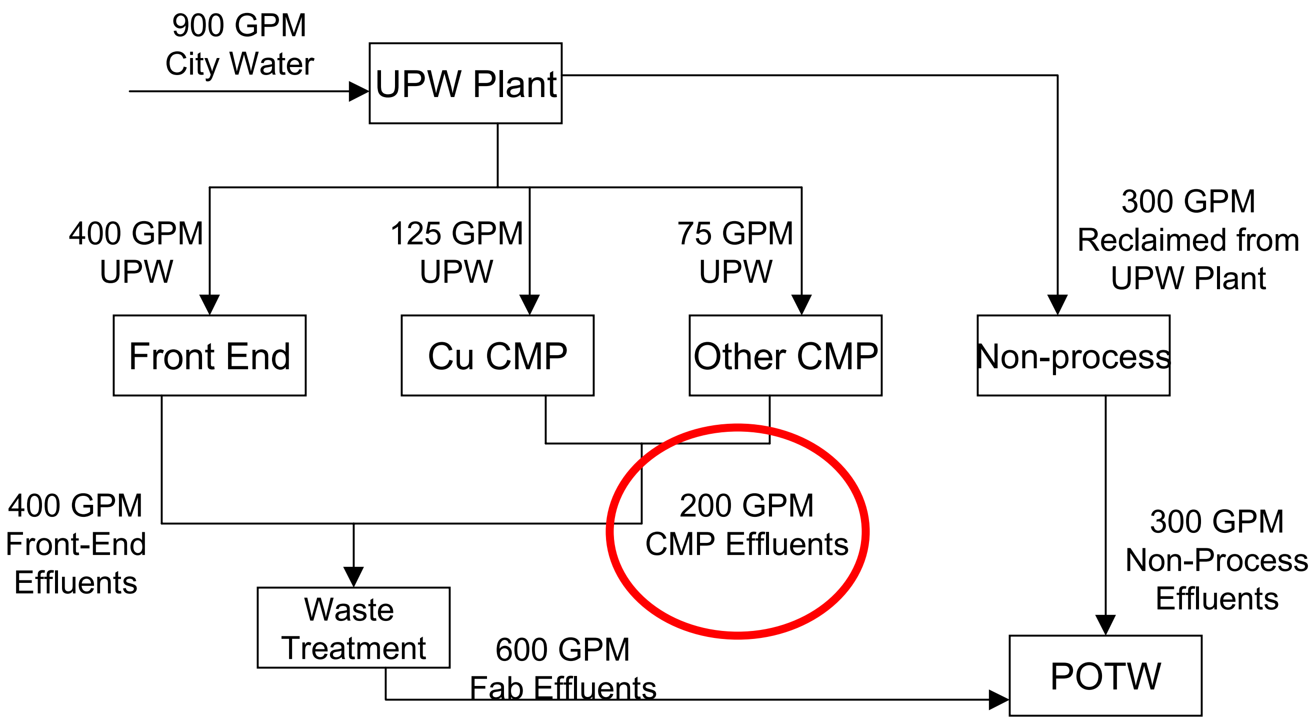
ITRS Goals‡

- Net feed water consumption drop from 13 gal/in^2 (of silicon) to 2 gal/in^2 by 2008
- Obtain environmental sustainability through waste management

† Corlett, G. *Advancing Applications in Contamination Control* 2000, 3(11), 9.
‡ Semiconductor Industry Association *International Technology Roadmap for Semiconductors: 1999 edition*; International SEMATECH: Austin, Texas, 1999; pg. 253.

ITRS Technology Barrier:
Waste Production vs. Environmental Regulations

Single fabrication plant produces 200 GPM of CMP effluent.†



† Maag, Benoit, "Copper CMP Effluent Flow in a Semiconductor Facility", NSF/SRC ERC for Environmentally Benign Semiconductor Manufacturing TeleSeminar, April 6, 2000

ITRS Technology Barrier: Waste Production vs. Environmental Regulations (cont.)

Waste Characteristics†

- 50-5000 ppm total suspended solids
- 0.1-50 ppm soluble copper

Environmental Regulations†

Waste must be reduced to the following levels prior to discharge to waste treatment system:

- < 5 ppm total suspended solids
- 0.1-2 ppm soluble copper
- Regulations vary according to location.
  - San Jose Code Limitations:‡ Cu = 2.7 ppm
  - Austin Code Limitations:‡ Cu = 1.9 ppm

† Raghavan, S. *Treatment of CMP Wastes*; Fourth Year Annual Report of the NSF/SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing on Grant EEC-9528813; University of Arizona: Tucson, Arizona, 2000; Vol. II, pg. 30.

‡ Corlett, G. *Advancing Applications in Contamination Control* December 1998, pg. 19.

Forced-Flow Electrophoresis (FFE)

Research Objectives

- Liquid/solid separation
  - good performance at high concentrations; retard filter cake buildup
  - create possibilities for water recycle/reuse
- Copper removal from waste stream

ESH Impact

- Recovery and recycle of water
- Help achieve ITRS goals for environmental sustainability through waste management
- Compliance with environmental regulations for waste streams

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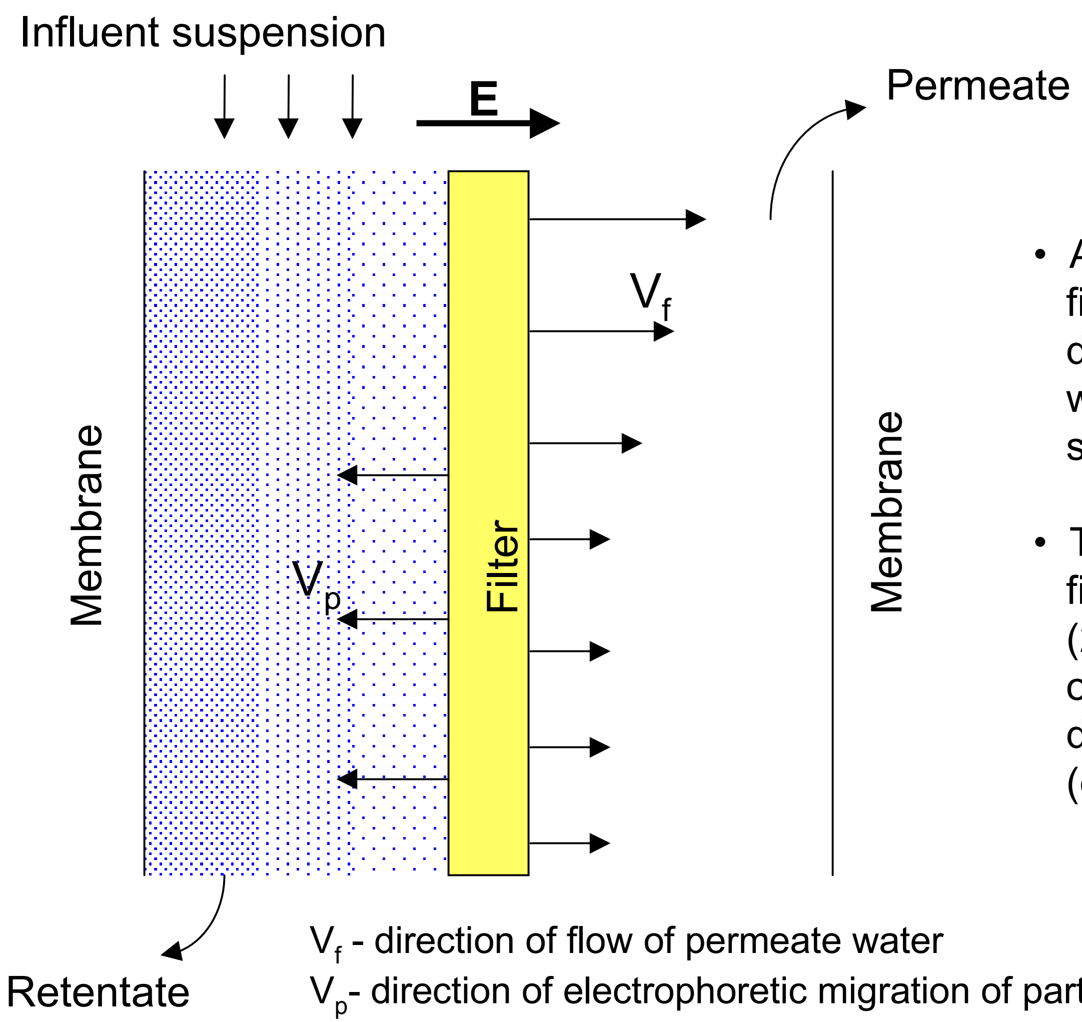
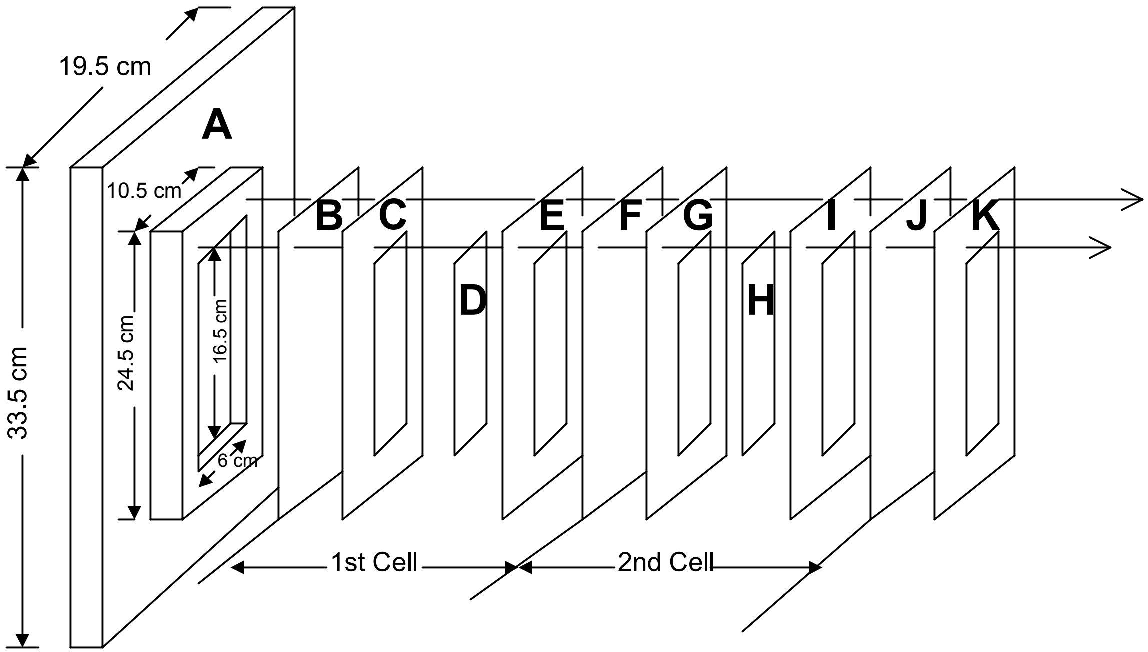
FFE: Cross-Flow Filtration with Electric Field



- An electric field **E** enhances cross-flow filtration process by electrophoretically driving particles away from filter surface, while driving electrodialysis of ionic solutes (e.g. Cu)
- Thus: (1) filter cake is suppressed and filter effectiveness maintained; and (2) the permeate is either enriched with, or depleted of, ionic solutes (including Cu), depending on the type of membrane used (e.g. cation exchange or anion exchange)

V_f - direction of flow of permeate water
V_p- direction of electrophoretic migration of particles

Expanded FFE Cell Assembly

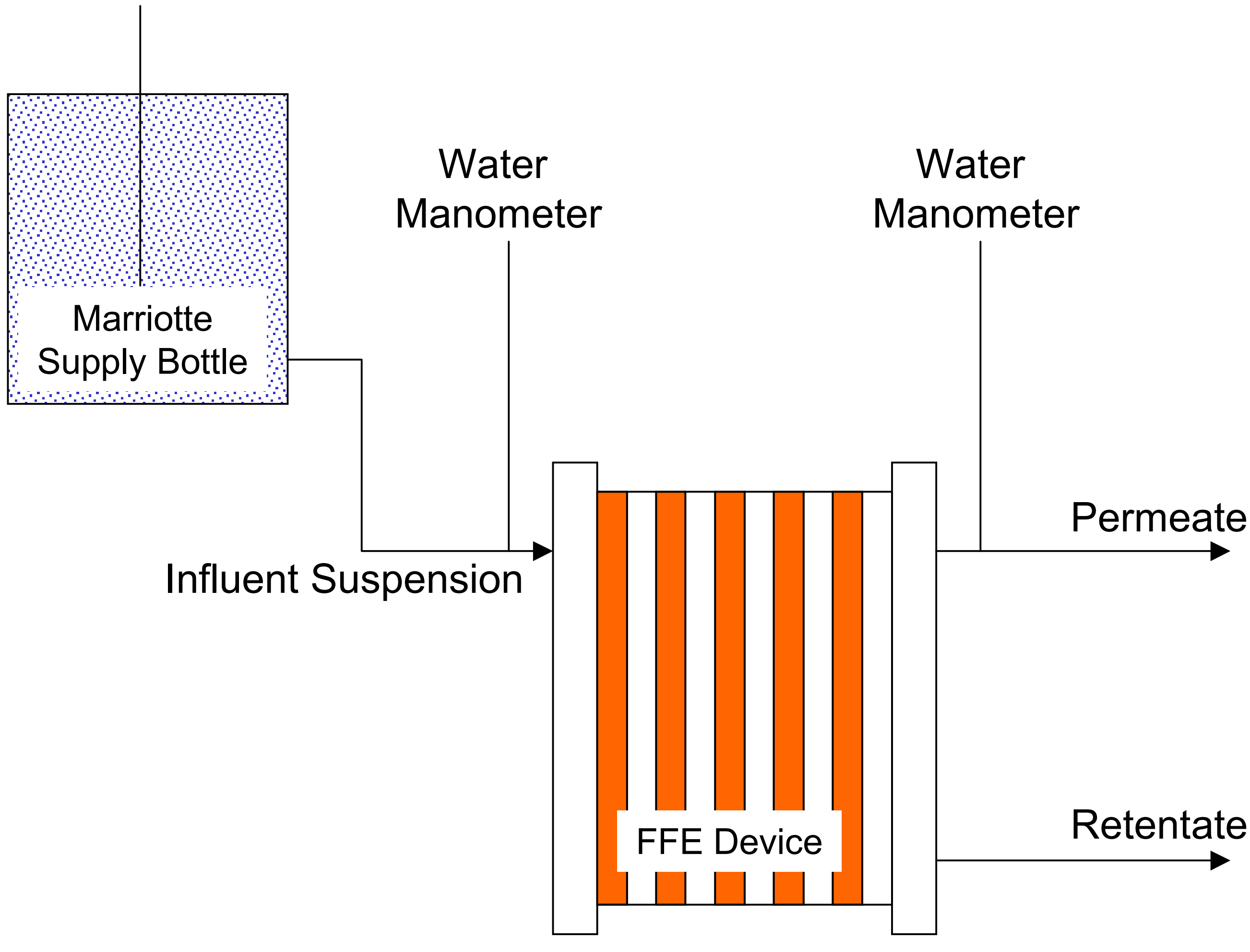


A End plate with Platinum Electrode
B Dialyzing Membrane
C Input Spacer for 1st Cell
D Micro Filter (Whatman, 20 μm)
E Output Spacer for 1st Cell
F Dialyzing Membrane
G Input Spacer for 2nd Cell
H Micro Filter (Whatman, 20 μm)
I Output Spacer for 2nd Cell
J Dialyzing Membrane
K Input Spacer for 3rd Cell

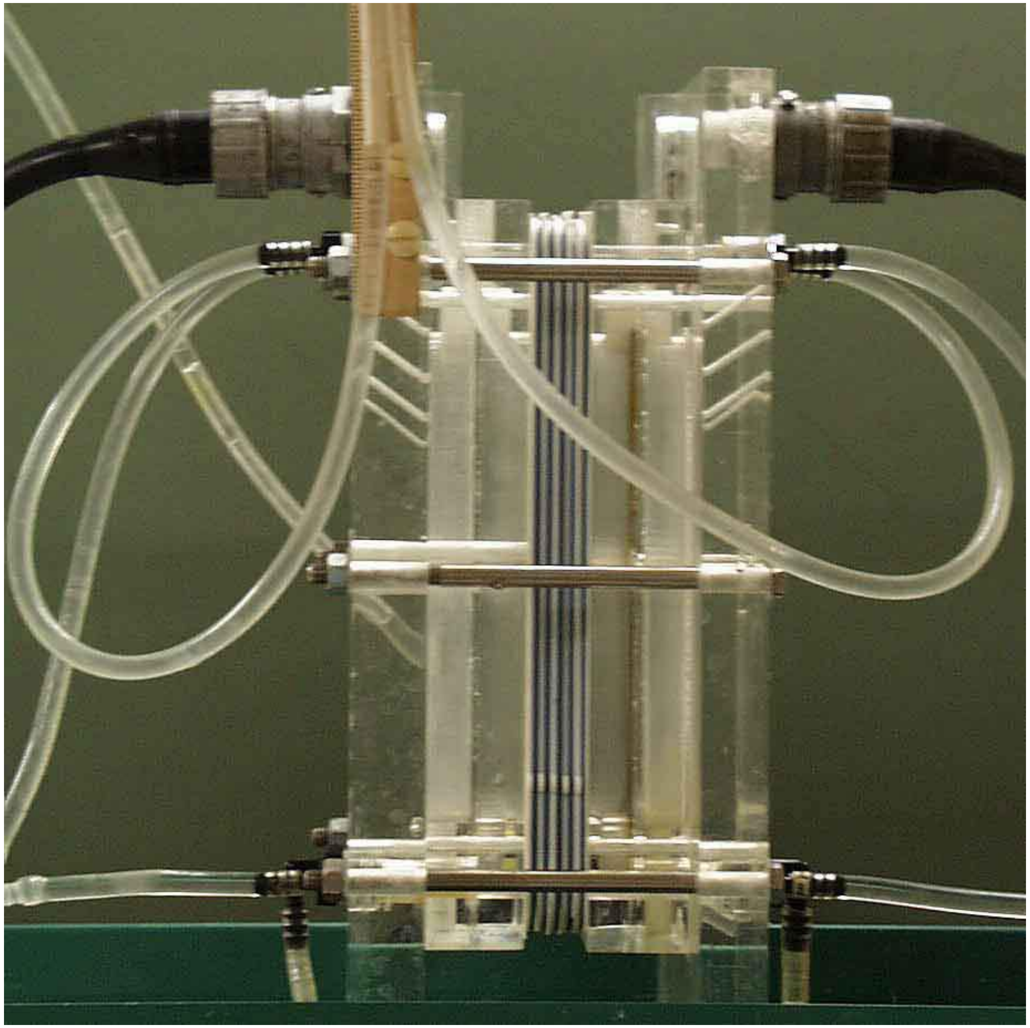
Device Components and Operating Conditions

- Electrodes: platinum
- Membranes: regenerated cellulose
  (weak cation exchange properties)
- Filters: Whatman®, 20 μm porosity
- Influent flow rate: 80 ml/min
- Permeate and retentate flow rate: 40 ml/min
- Effective volume: 180 ml

Entire FFE Apparatus



FFE Apparatus



- FFE method developed by:
  Bier, M. et al., **1959**
- Additional research on FFE:
  Henry, et al., **1977**
  Wakeman, et al., **1987**
- Review of FFE
  Huotari, et al., **1999**

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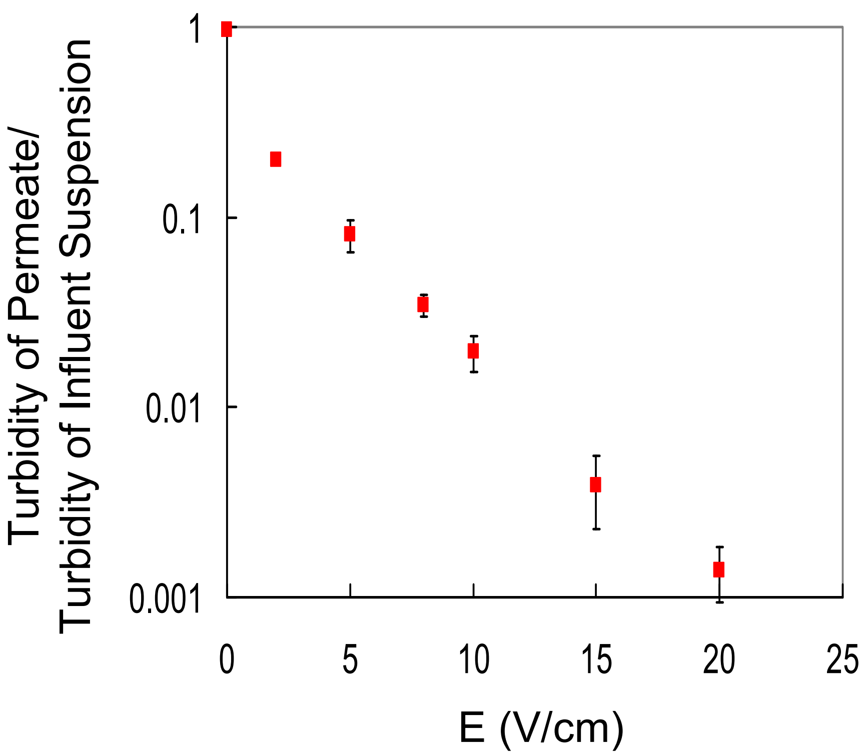
CMP Waste Characteristics

Waste Stream	Turbidity (NTU)	Conductivity (μS/cm)	pH	Cu^{++} Conc. (ppm)
Model Oxide	450†	230	10.5	—
Texas Instruments	1550	160	9.0	—
Model Copper	410‡	570	5.0	20

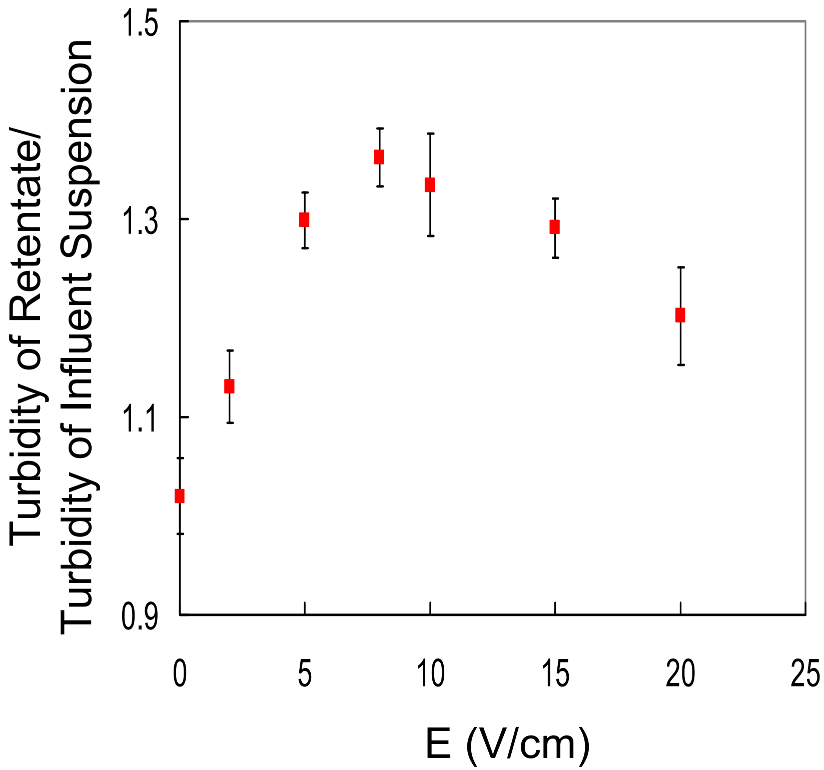
† 1000 ppm Klebosol® colloidal silica; mean particle size, 80 nm
‡ 900 ppm Klebosol® colloidal silica; mean particle size, 80 nm

Electrophoretic Filtration of Particles
for Model Oxide CMP Waste

Permeate



Retentate

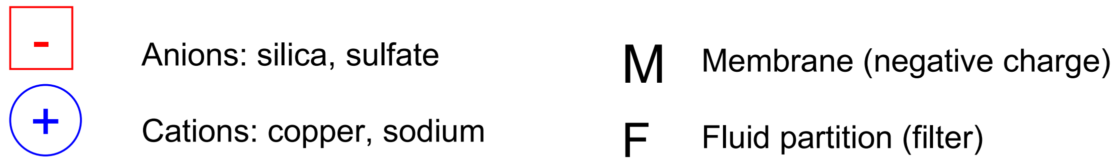


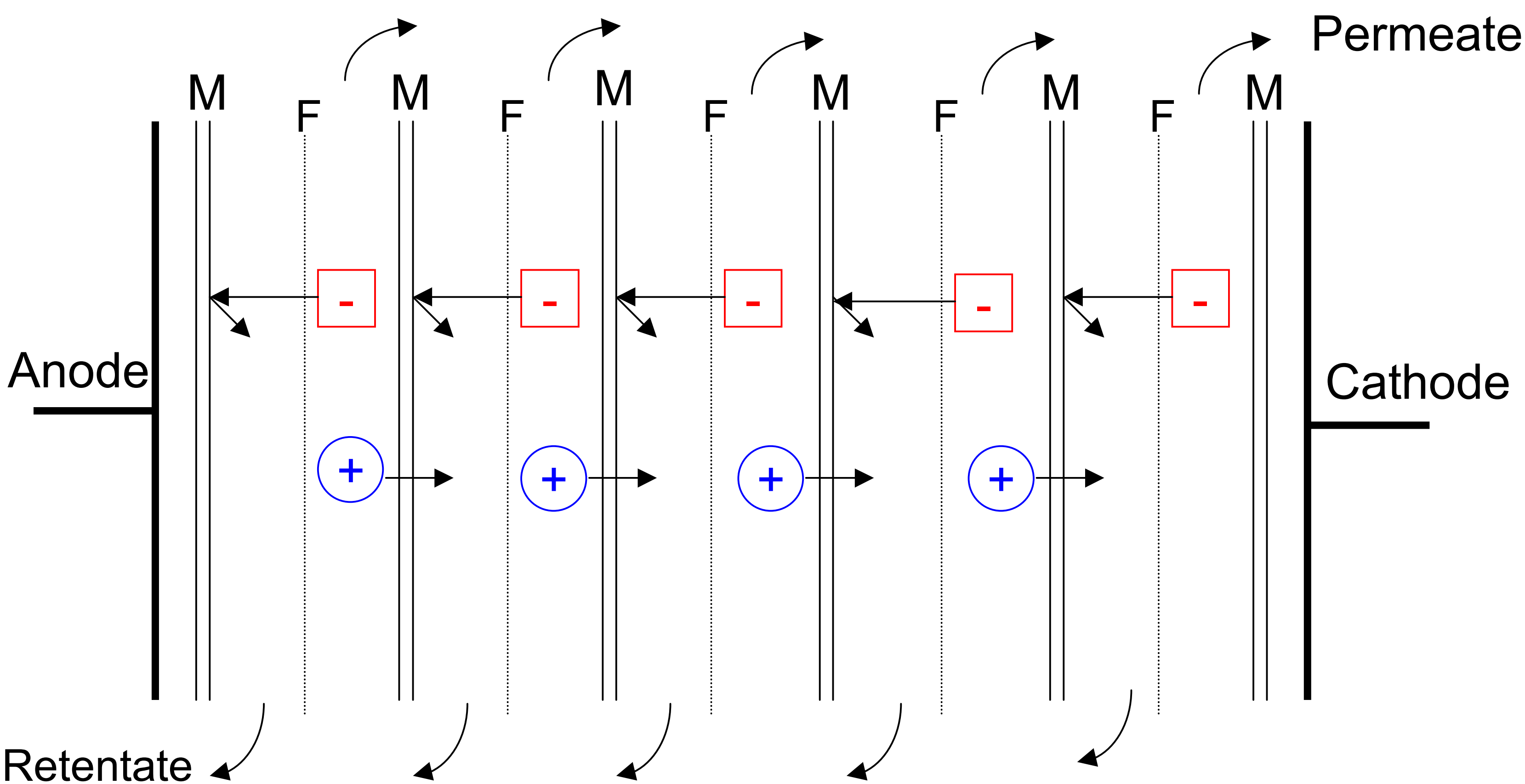
Influent Suspension Characteristics:

[SiO_2] = 1000 ppm — Conductivity = 230 μS/cm

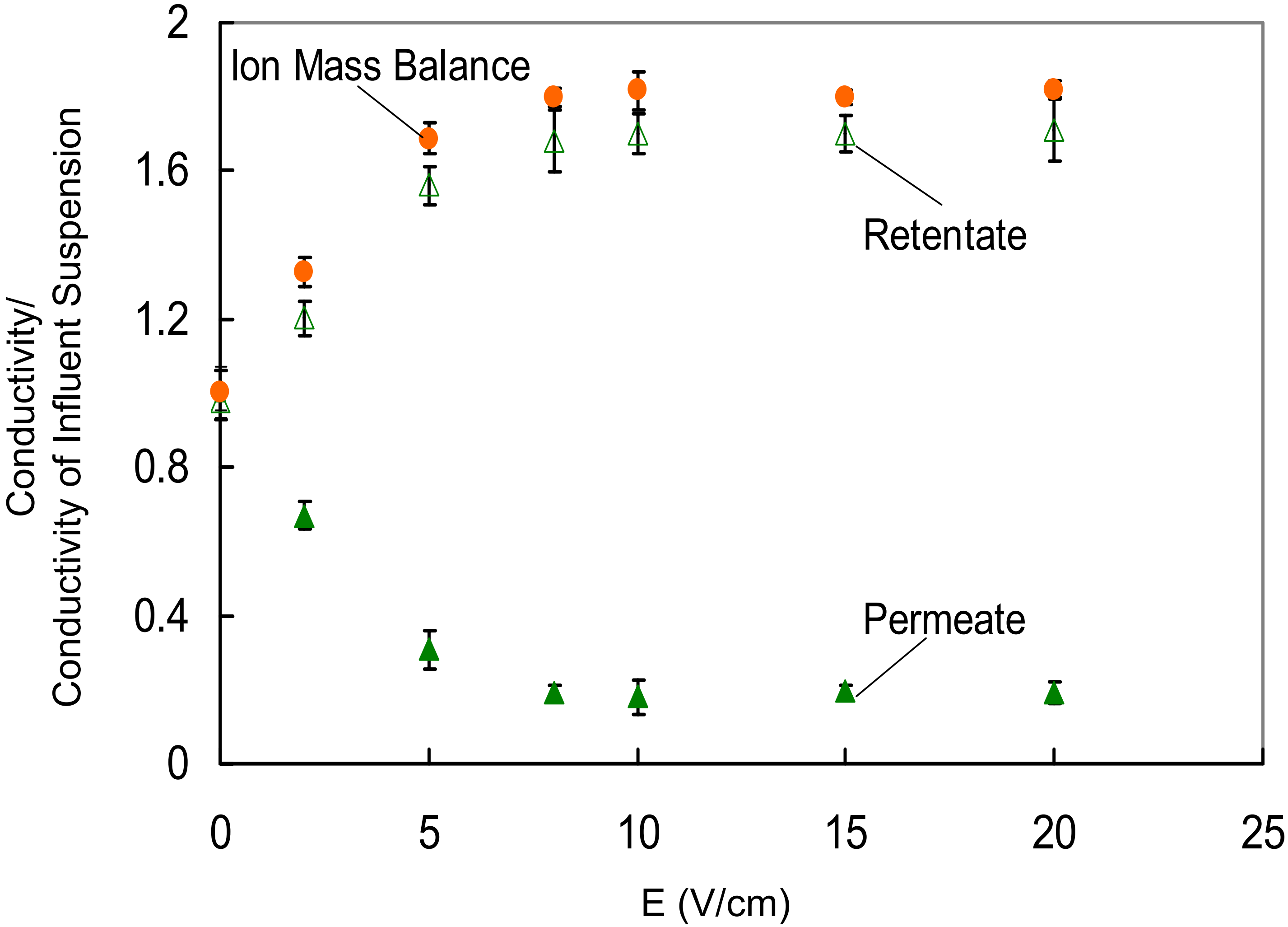
Turbidity = 450 NTU — pH = 10.5

Electrodialysis Mechanism



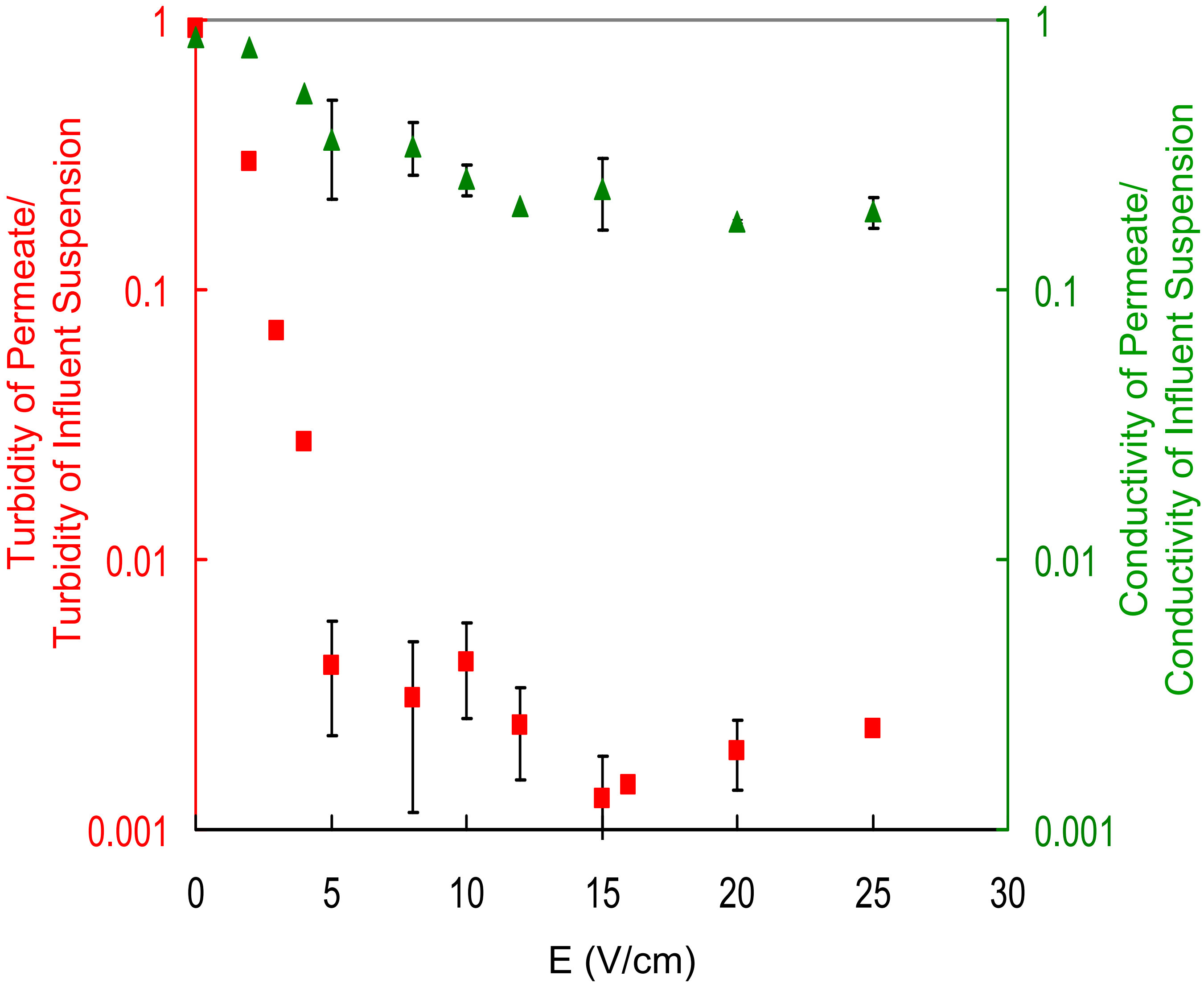


Electrodialysis of Ionic Solutes
for Model Oxide CMP Waste



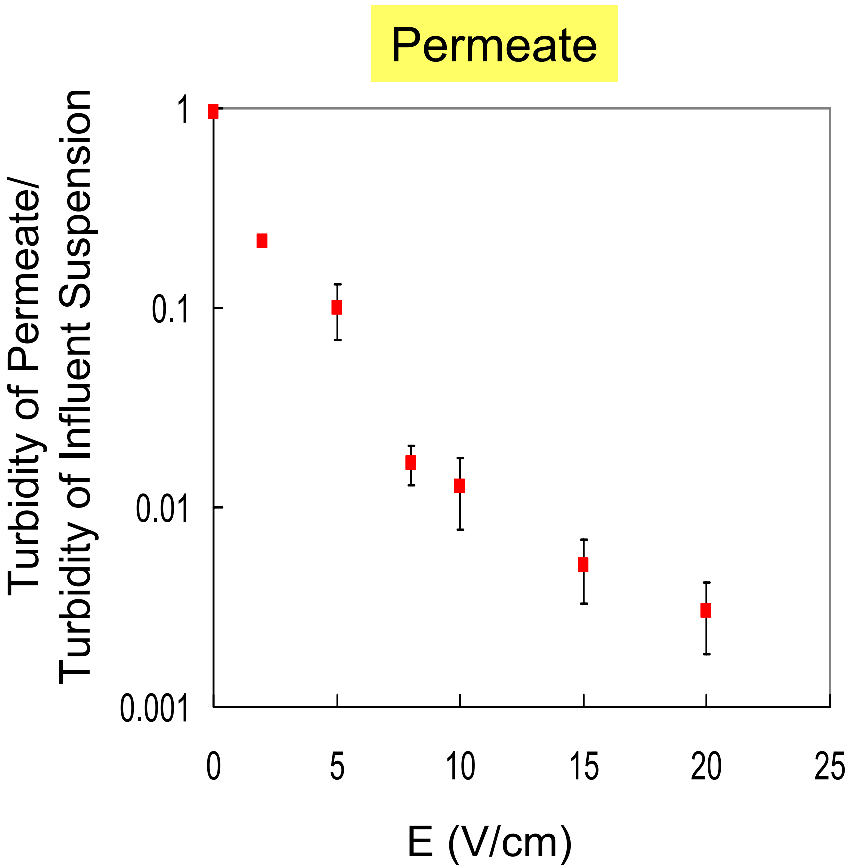
Influent Suspension Characteristics:
$[SiO_2]$ = 1000 ppm
Turbidity = 450 NTU
Conductivity = 230 μS/cm
pH = 10.5

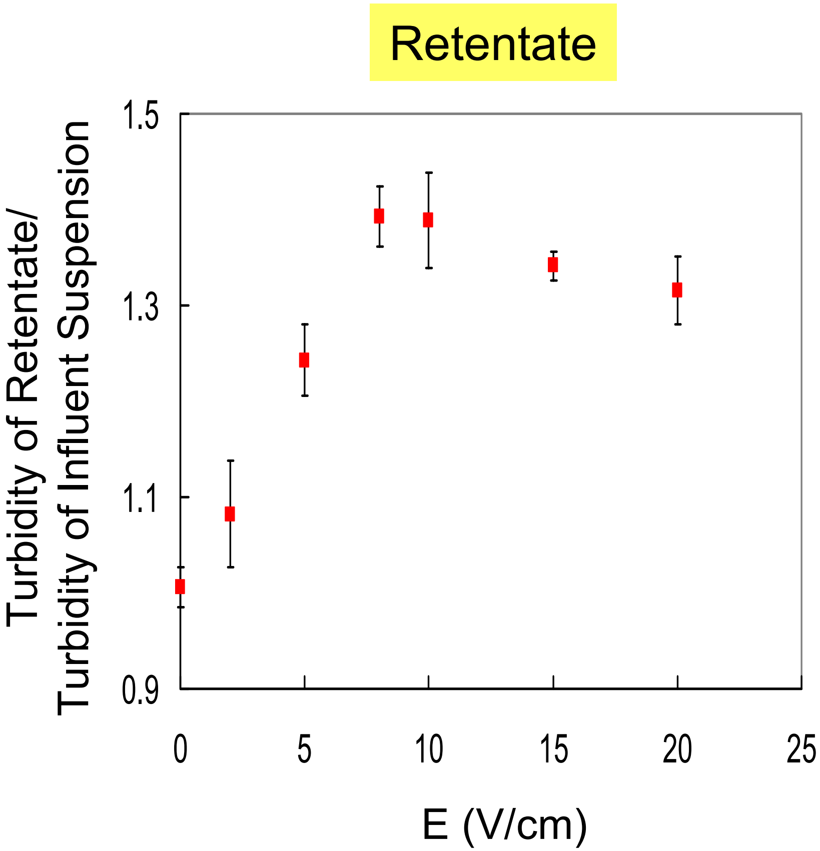
FFE of Industrial Oxide CMP Waste
from Texas Instruments Inc.



Influent Suspension
Characteristics:
Turbidity = 1550 NTU
Conductivity = 160 μS/cm
pH = 9.0

Electrophoretic Filtration of Particles
for Model Copper CMP Waste





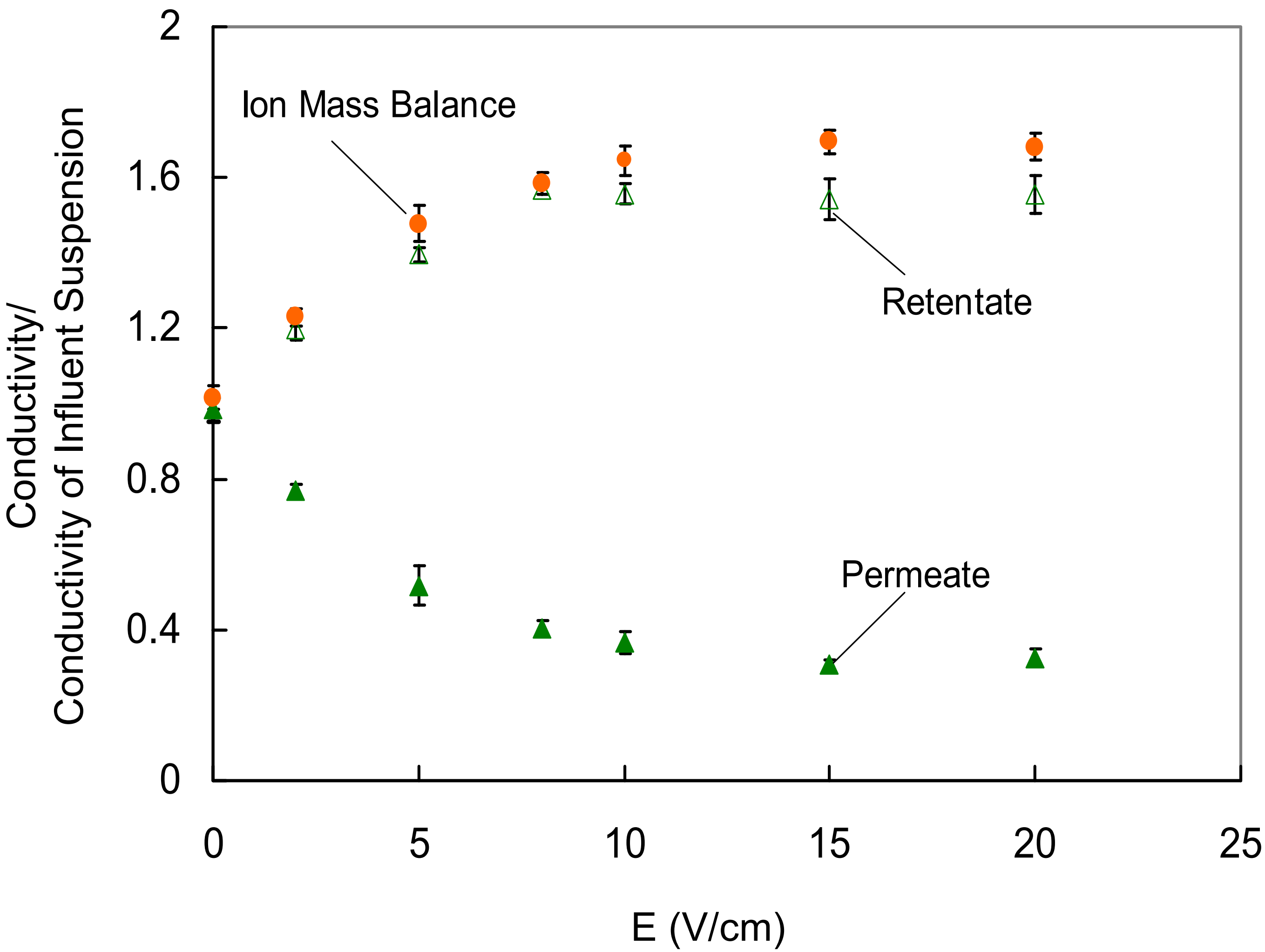
Influent Suspension Characteristics:

[SiO_2] = 900 ppm
[Cu] = 20 ppm

[Citric Acid] = 66 ppm
[BTA] = 37 ppm

Conductivity = 570 μS/cm
Turbidity = 410 NTU
pH = 5.0

Electrodialysis of Ionic Solutes
for Model Copper CMP Waste



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[SiO_2] = 900 ppm
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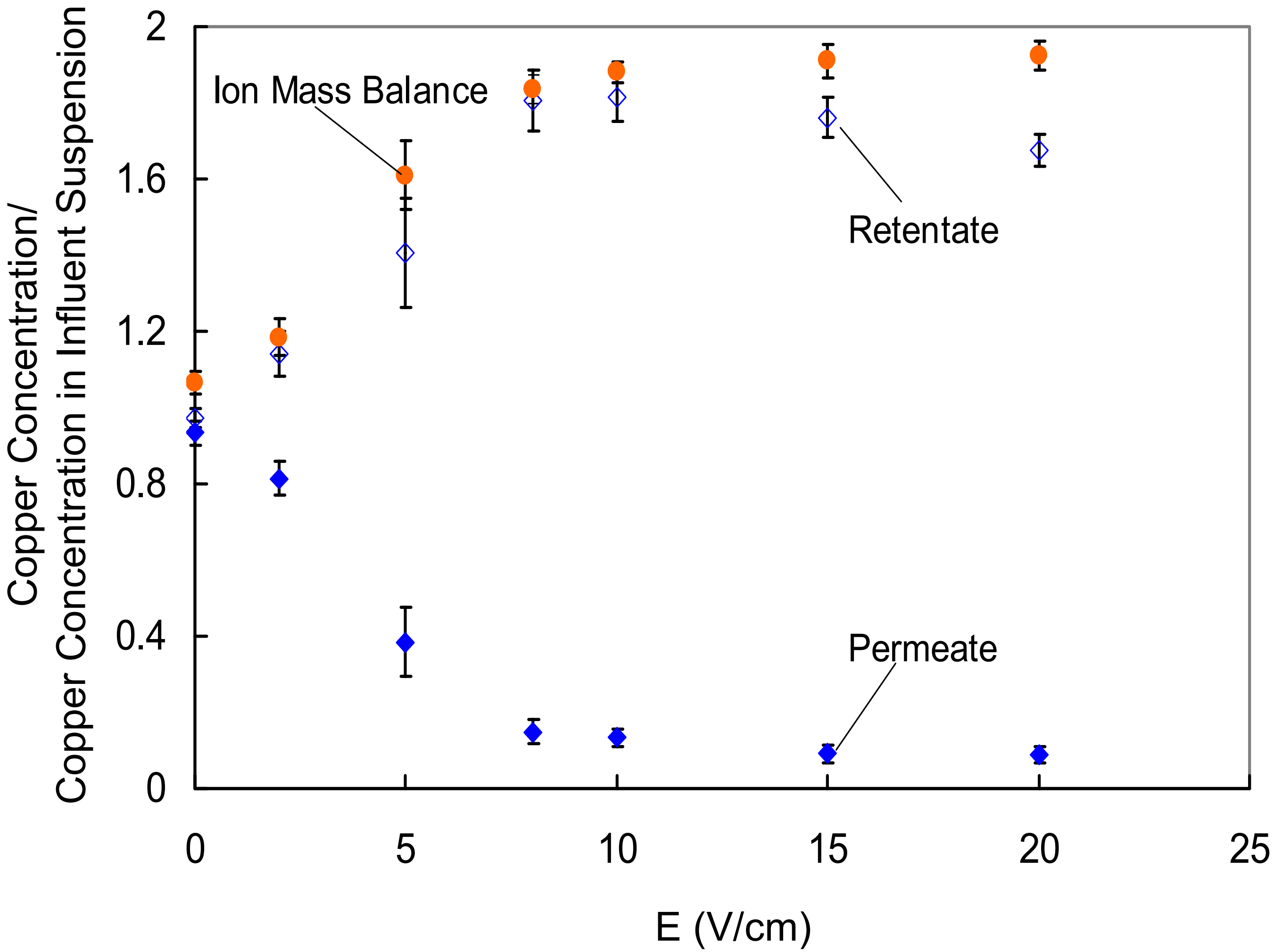
[Citric Acid] = 66 ppm
[BTA] = 37 ppm
Turbidity = 410 NTU
Conductivity = 570 μS/cm
pH = 5.0

Electrodialysis of Copper
for Model Copper CMP Waste



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[SiO_2] = 900 ppm
[Cu] = 20 ppm
[Citric Acid] = 66 ppm
[BTA] = 37 ppm
Turbidity = 410 NTU
Conductivity = 570 μS/cm
pH = 5.0

Energy Consumption: Forced-Flow Electrophoretic Filtration vs. Mechanical Filtration

Filtration Technique	Energy Consumption/ Permeate Flow Rate
Ultrafiltration (with 45% pump efficiency)	5 kJ/gallon of permeate
FFE Industrial Oxide CMP Waste Conductivity = 160 μS/cm	3 kJ/gallon of permeate
FFE Model Copper CMP Waste Conductivity = 570 μS/cm	20 kJ/gallon of permeate

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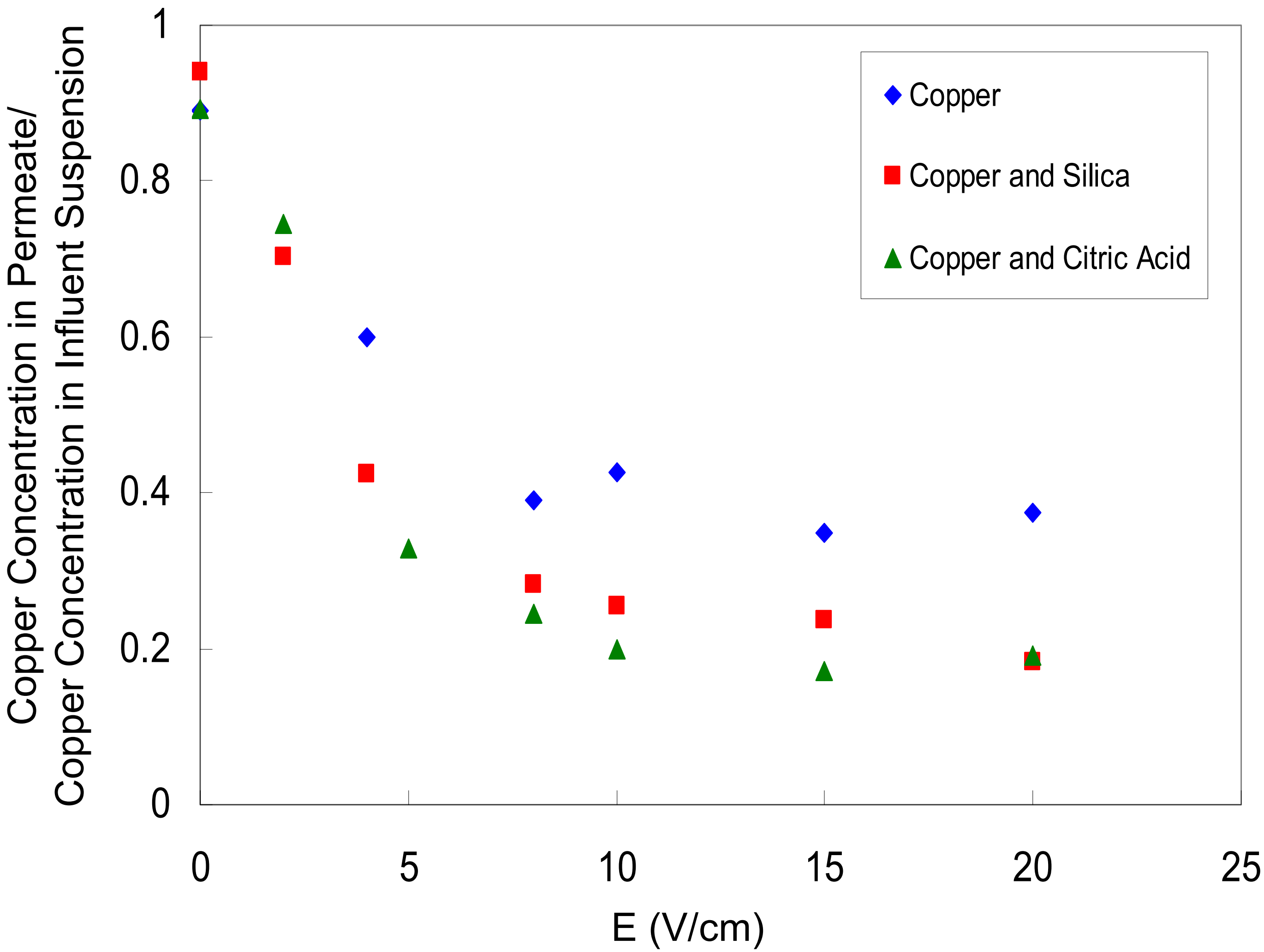
Effects of Various Additives on FFE Process:

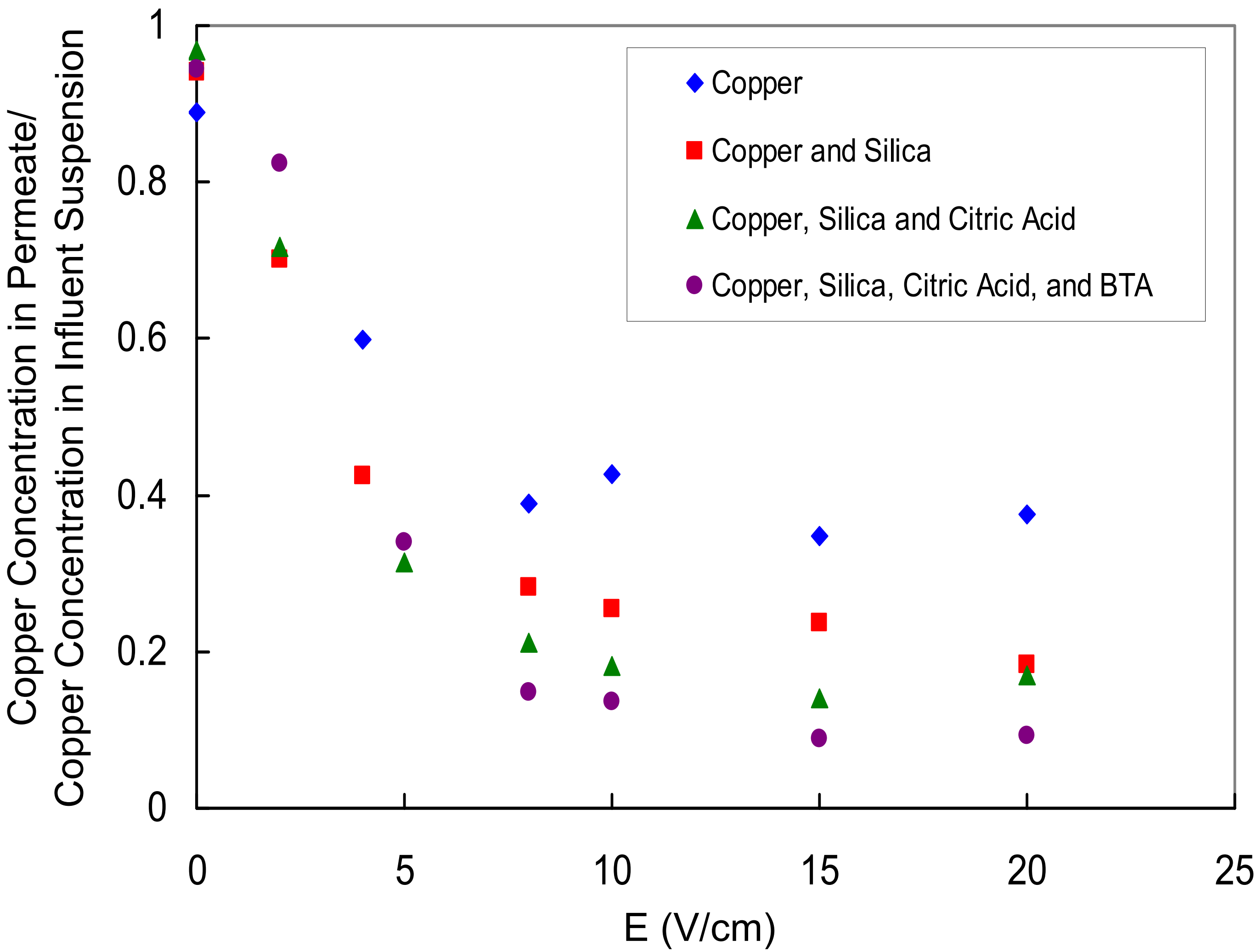
Electrodialysis of Copper



Influent Suspension Characteristics:
Conductivity = 570 μS/cm
pH = 5.0

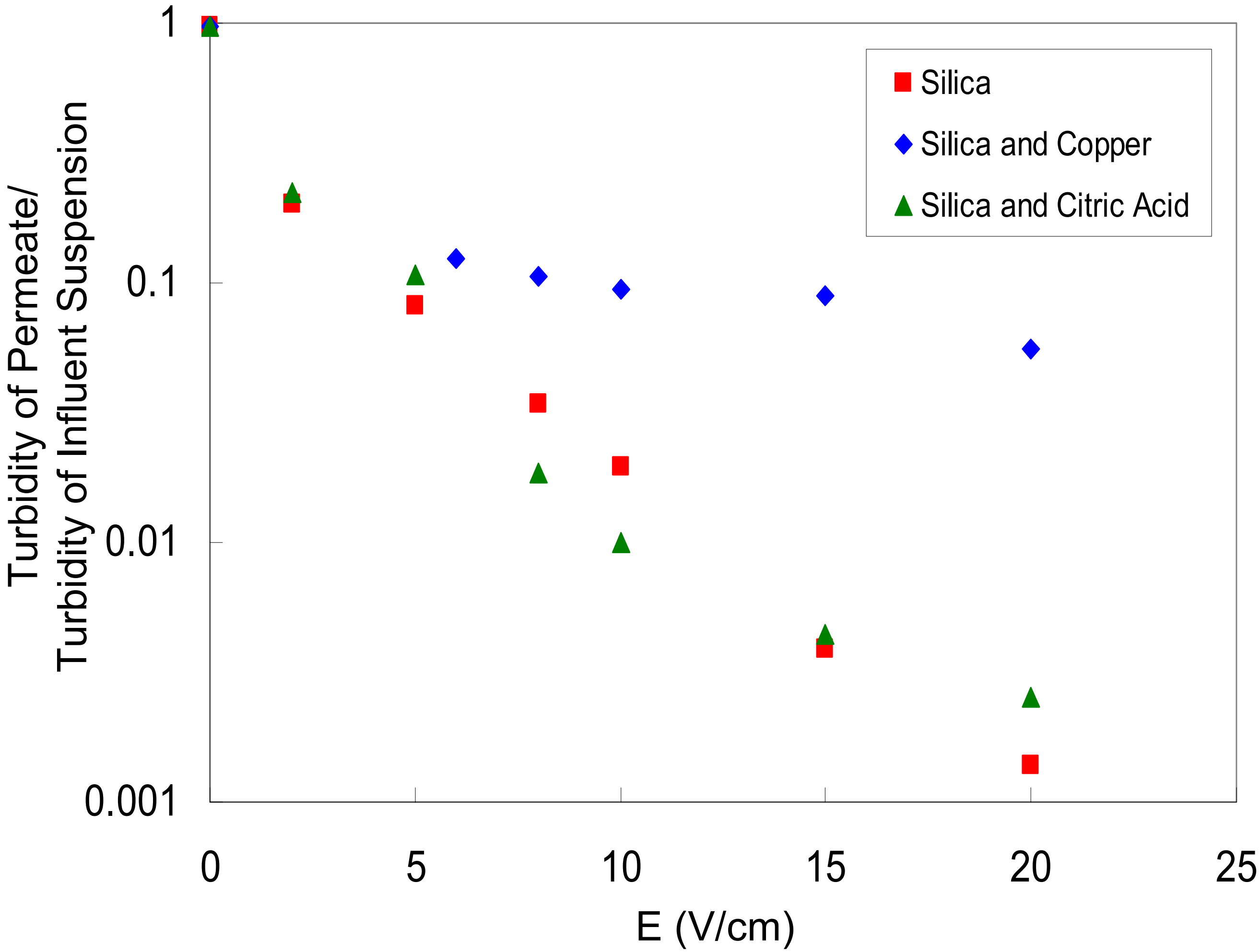
Effects of Various Additives on FFE Process

Electrodialysis of Copper (cont.)



Influent Suspension Characteristics:
Conductivity = 570 μS/cm
pH = 5.0

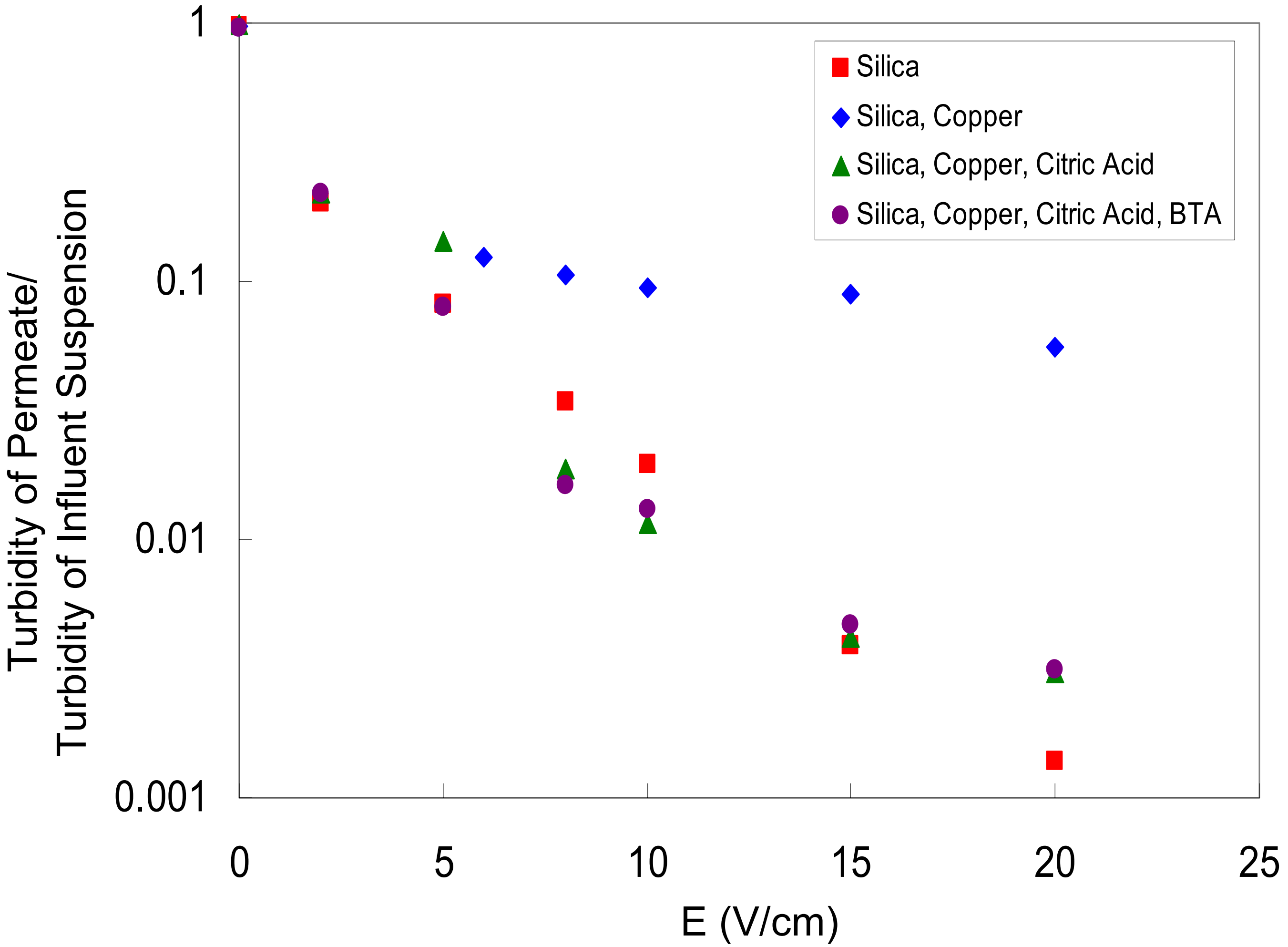
Effects of Various Additives on FFE Process
Electrophoretic Filtration of Particles (cont.)



Influent Suspension Characteristics:
Conductivity = 570 µS/cm
pH = 5.0

Effects of Various Additives on FFE Process

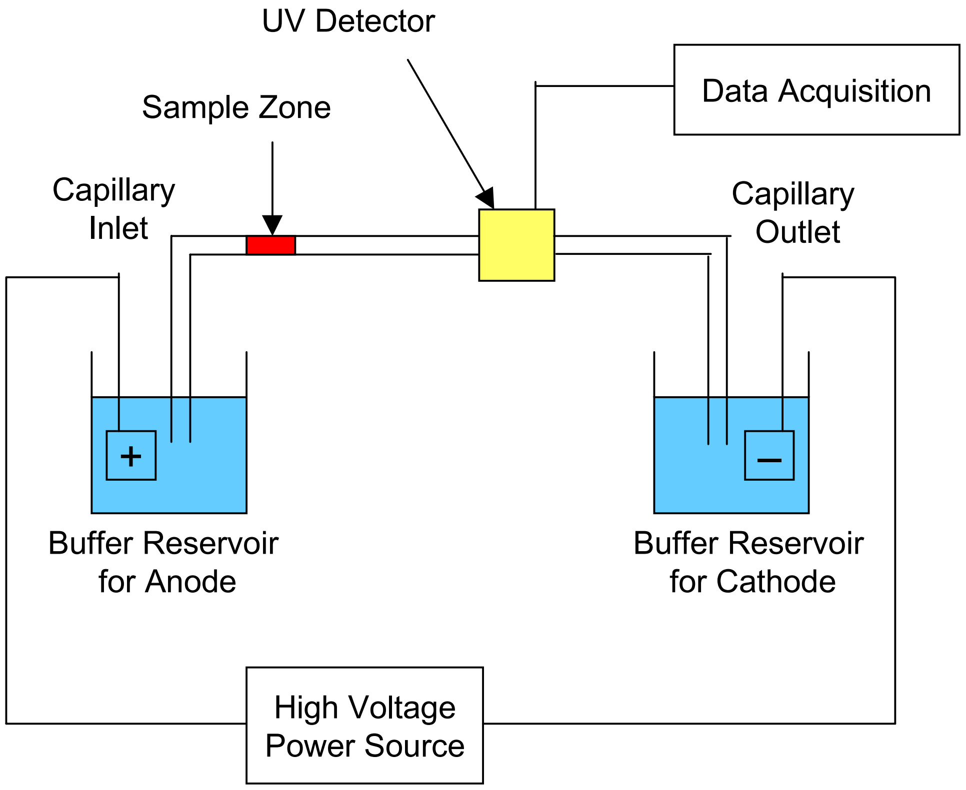
Electrophoretic Filtration of Particles (cont.)



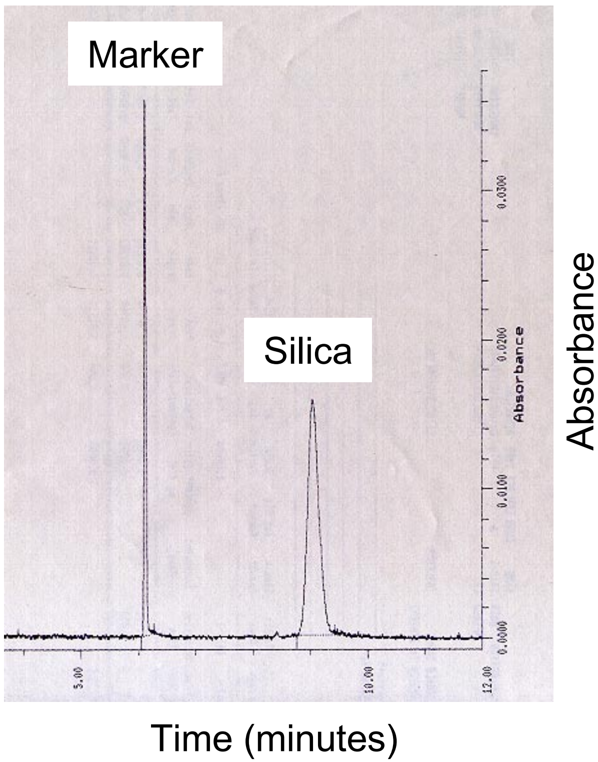
Influent Suspension Characteristics:
Conductivity = 570 μS/cm
pH = 5.0

Effect of Various Additives on Electrophoretic Mobility of Particles and Copper

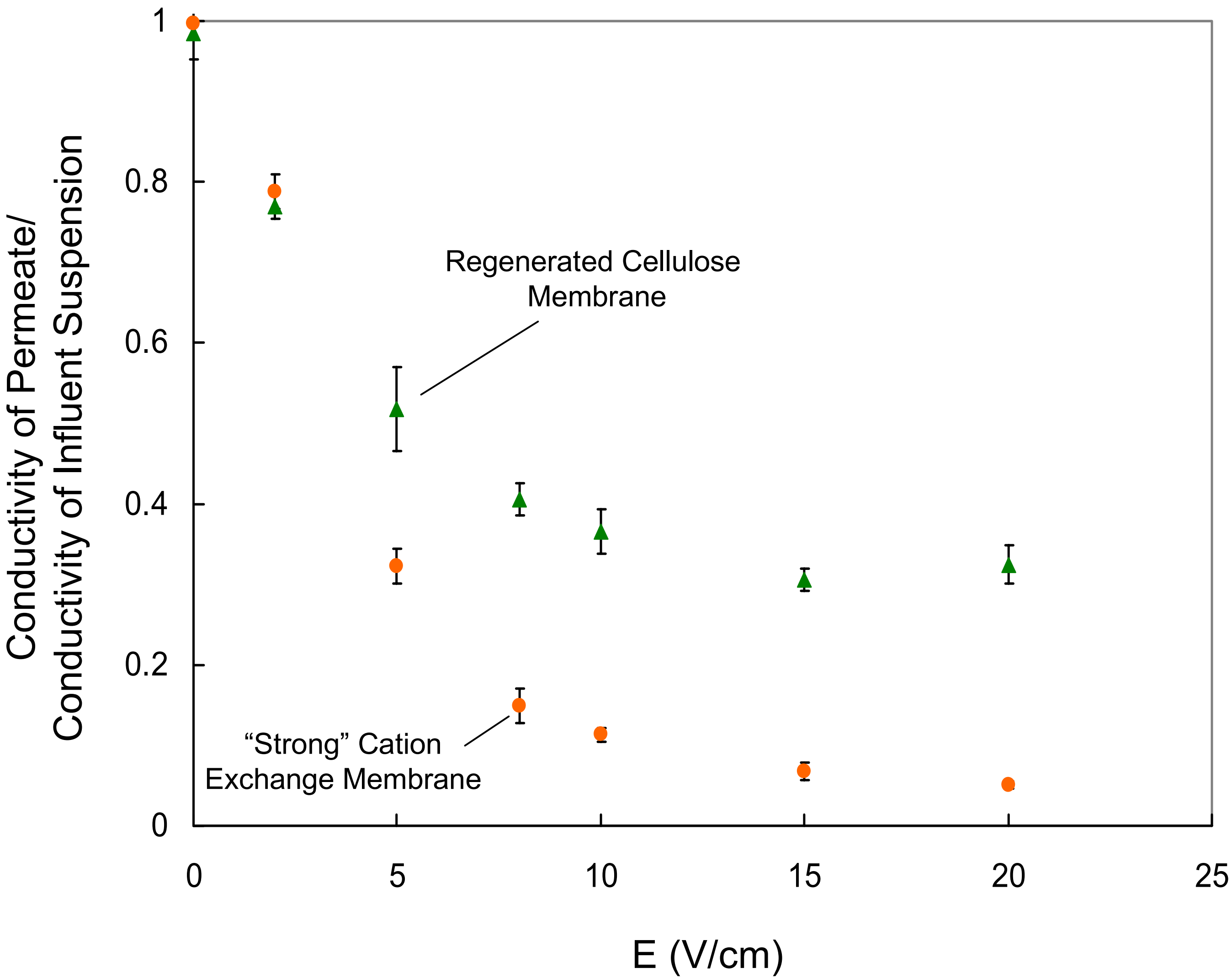
Capillary Electrophoresis



- Additives effect electrophoretic mobilities of particles or copper?
- Additives effect distribution of particle mobilities?



FFE with Strong Cation Exchange Membranes



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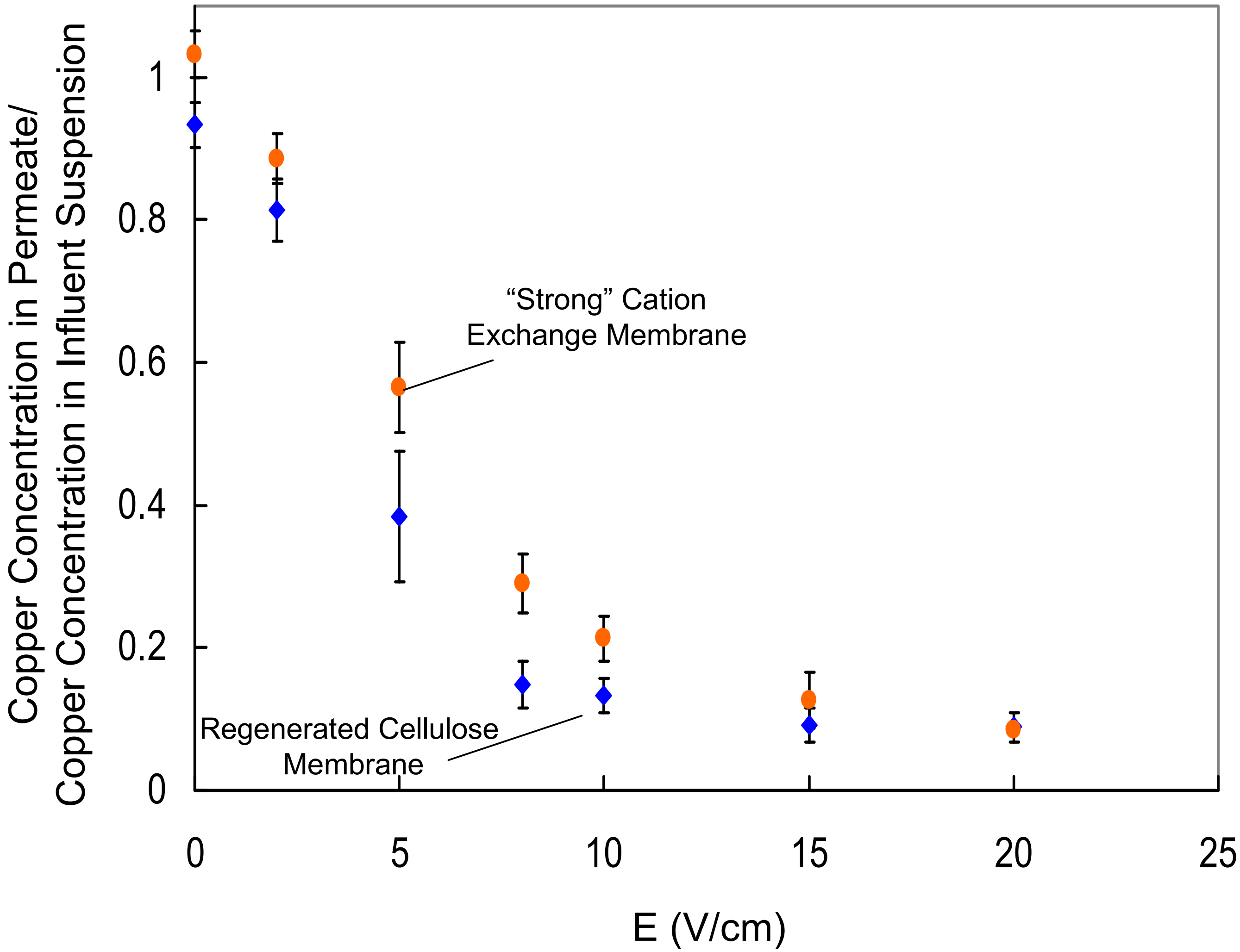
FFE with Strong Cation Exchange Membranes (cont.)



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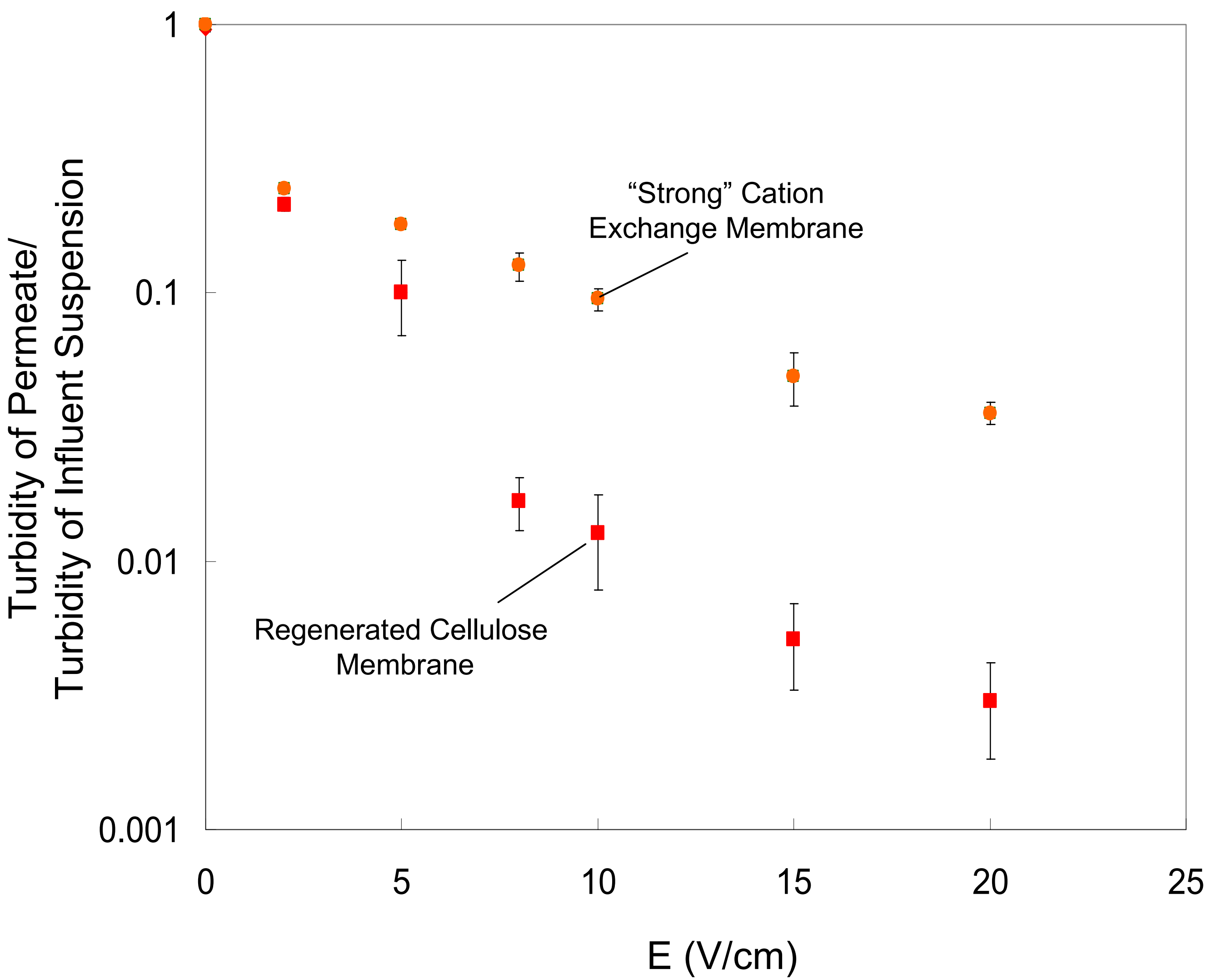
- pH = 5.0

FFE with Strong Cation Exchange Membranes (cont.)



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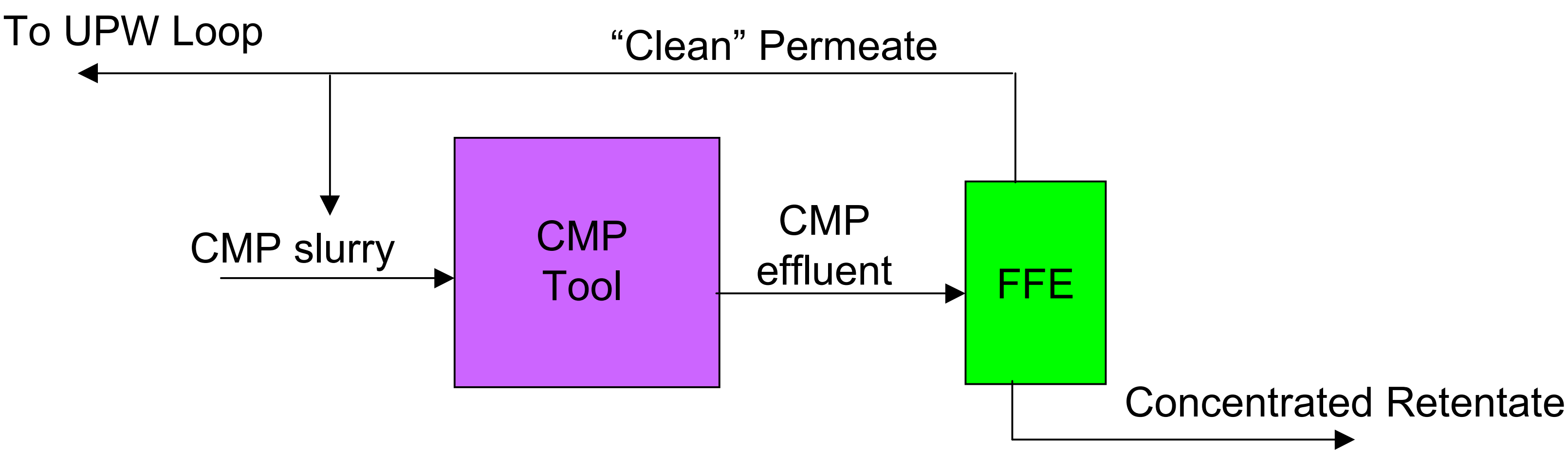
Potential Industrial Applications

1. Use as filtration device on each individual CMP tool.

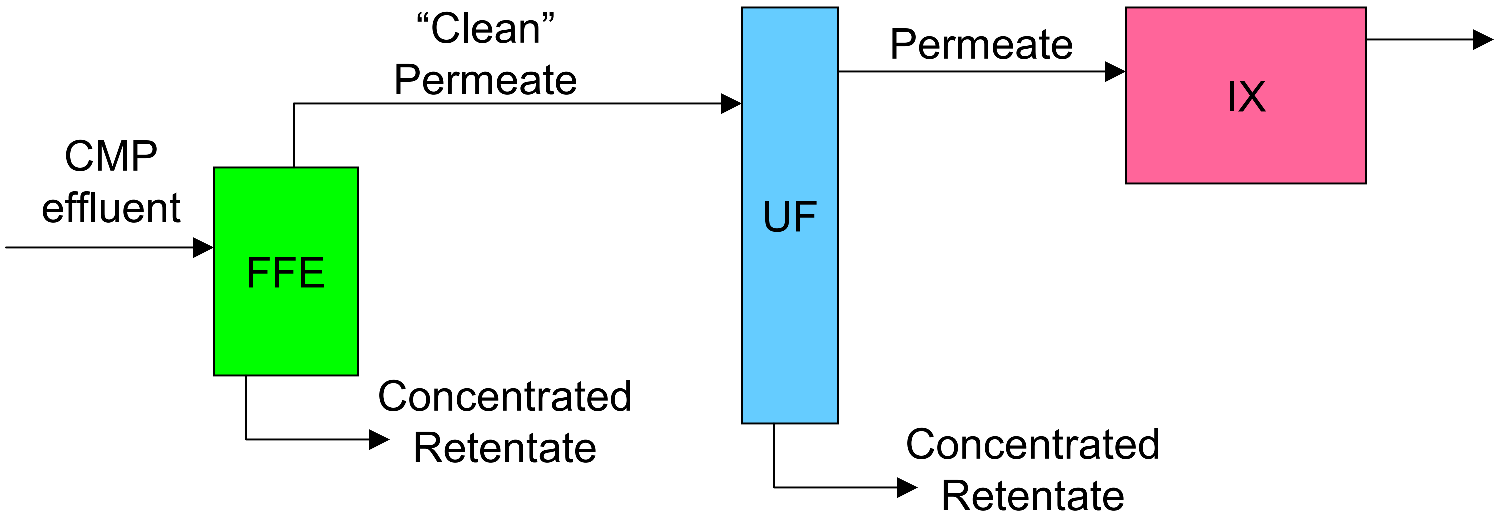


- Forced-flow electrophoresis device (FFE) could act as a CMP tool "kidney" that could be switched on and off according to demands of CMP tool.

- Permeate stream, reduced of particle and copper contamination, could be recycled back into the CMP process.

Potential Transfer of Technology (cont.)

2. Use immediately before standard ultra-filtration (UF) and ion-exchange (IX) processes to pre-treat CMP waste.



- Forced-flow electrophoresis pre-treatment will yield less consumables (e.g. UF cartridges, ion-exchange resin, etc.)

Industry Interaction

The following companies have provided assistance:

- **Semiconductor Research Corporation**
- **Texas Instruments**, *Jeff Joiner and John DeGenova*
- **Ionics**, *Ted Prato and Russ MacDonald*
- **Pall Corporation**, *Joe O’Sullivan*

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Concluding Remarks

- Have demonstrated simultaneous removal of particles (ca. 90 to 99%) and ions (including >85% of Cu) from CMP permeate streams.

- Energy requirements are not significantly different from those of standard ultrafiltration.

- FFE may have the potential to serve as a CMP waste management device and could help the semiconductor industry comply with the environmental regulations for the waste streams.