Electrochemical Process Technologies for Water Processing

Presentation to

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Problem Background

- Over 250 drinking water systems exist for small communities in Puerto Rico that serve 25-500 individuals
- These sources are from ground and surface waters
- Flow rates are upwards of 50,000 gallons per day for a community of 500 people
- The EPA desires improved novel filtration and chlorination methods that can disinfect and filter these drinking water sources
- To address this need, Reactive Innovations, LLC has been developing an on-site hypochlorite generator that can continuously chlorinate surface groundwater

Puerto Rico Small Community Water Quality Characteristics

- Semi-tropical island creates a high organic content in the water
- Water quality fluctuates significantly, especially in surface water where total suspended solids (TSS) change drastically
- Chlorine application rates vary from 3-4 ppm for surface water to 1-3 ppm for ground water
- High contamination levels in these water systems indicate the need for more dependable and cost effective solutions

	Surface		Ground	
	raw	**distributed**	**raw**	**distributed**
turbidity (NTU)	1.8	4.8	0.3	0.5
total coliforms (per ml)	900	60	6	13
fecal coliforms (per ml)	100	10	5	0.25
Escherichia coli (per ml)	20	1	5	13
fecal streptococci (per ml)	30	3	0	1
heterotrophic plate count (per ml)	4000	10000	1200	110
free chlorine (ppm)		0.38		0.36
total chlorine (ppm)		0.42		0.4

Competing Technologies

Water treatment with shipped sodium hypochlorite

- Issues with this method
  - Unfeasible to transport relatively small quantities to remote areas
  - Hazards associated with transport and storage of bleach
  - High maintenance demand

Competing Technologies

Chlorine tablets

- Currently used in small Puerto Rican communities
- Issues with this method
  - Demands tablet delivery
  - Non-uniform disinfecting of water can be hazardous

Competing Technologies

On-site hypochlorite generators

- Technology: electrochemical chlor-alkali process
  - Uses sodium chloride solution and untreated water
  - Products: chlorine and sodium hydroxide (caustic soda)
  - Cl_2 and NaOH react to form sodium hypochlorite (NaOCl)
- Issues with current technology
  - Requires process water slipstreams to generator
    - Including additional valves, piping, maintenance
  - Salt and water process streams not separated
    - Relatively large reactor
    - Excess salt enters process water
  - 0.8% sodium hypochlorite product solution must be metered into process water

Technical Innovation

- The innovation for this process is a tubular electrochemical reactor that efficiently produces sodium hypochlorite in a design format that simplifies the balance of plant operation
- Two design modes under consideration

1) Traditional chlor-alkali process with hydrogen liberation

– Anode:	$2Na^+ + 2Cl^- \rightarrow Cl_2 + 2e^- + 2Na^+$	$E^o = -1.36V$	[1]
– Cathode:	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	$E^o = -0.828V$	[2]
– Overall:	$2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$	$E^o = -2.19V$	[3]

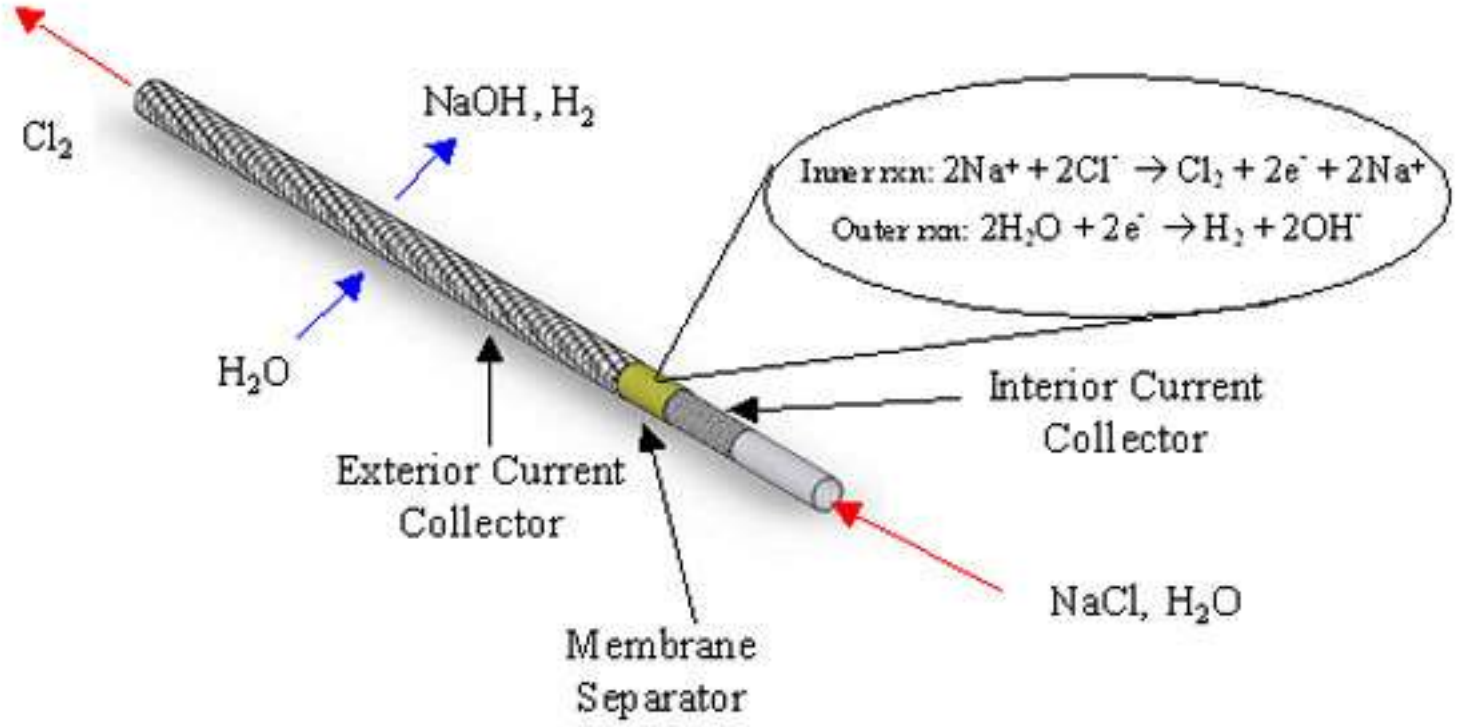
2) Air depolarized cathode to suppress hydrogen liberation

– Anode:	$2Na^+ + 2Cl^- \rightarrow Cl_2 + 2e^- + 2Na^+$	$E^o = -1.36V$	[4]
– Cathode:	$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$	$E^o = 0.40V$	[5]
– Overall:	$2NaCl + H_2O + 1/2O_2 \rightarrow Cl_2 + 2NaOH$	$E^o = -0.95V$	[6]

- These anode and cathode streams are mixed to form sodium hypochlorite
  - $Cl_2 + 2NaOH \rightarrow NaCl + H_2O + NaOCl$ [7]

Tubular Electrochemical Reactor Technology Platform

- Tubular cell design schematic



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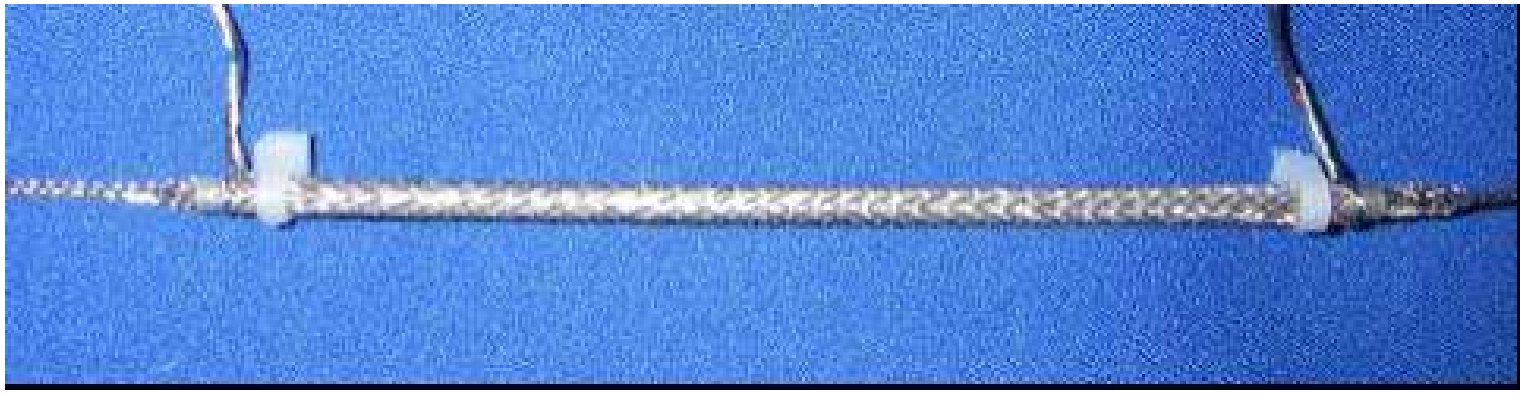
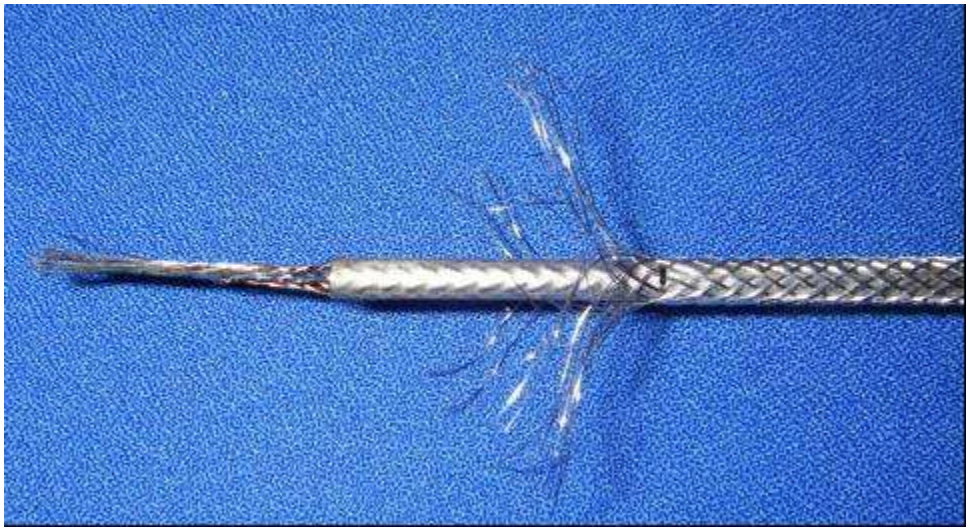
Tubular Membrane and Electrode Assemblies

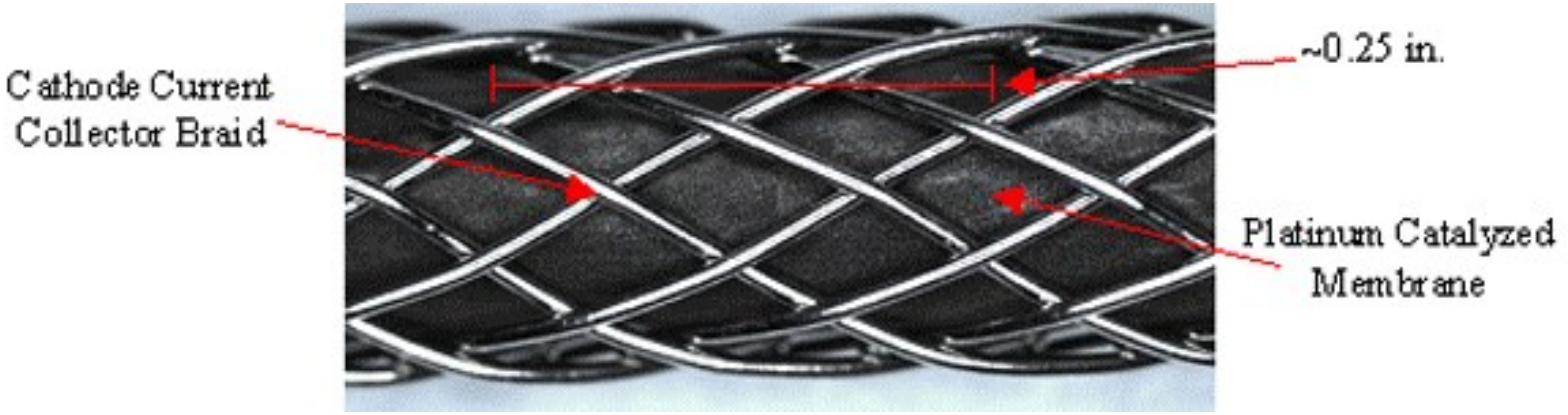
- MEA: membrane-and-electrode assembly



- Tubular catalyzed Nafion proton-exchange membrane with wire braided at its inner and outer surfaces for current collection

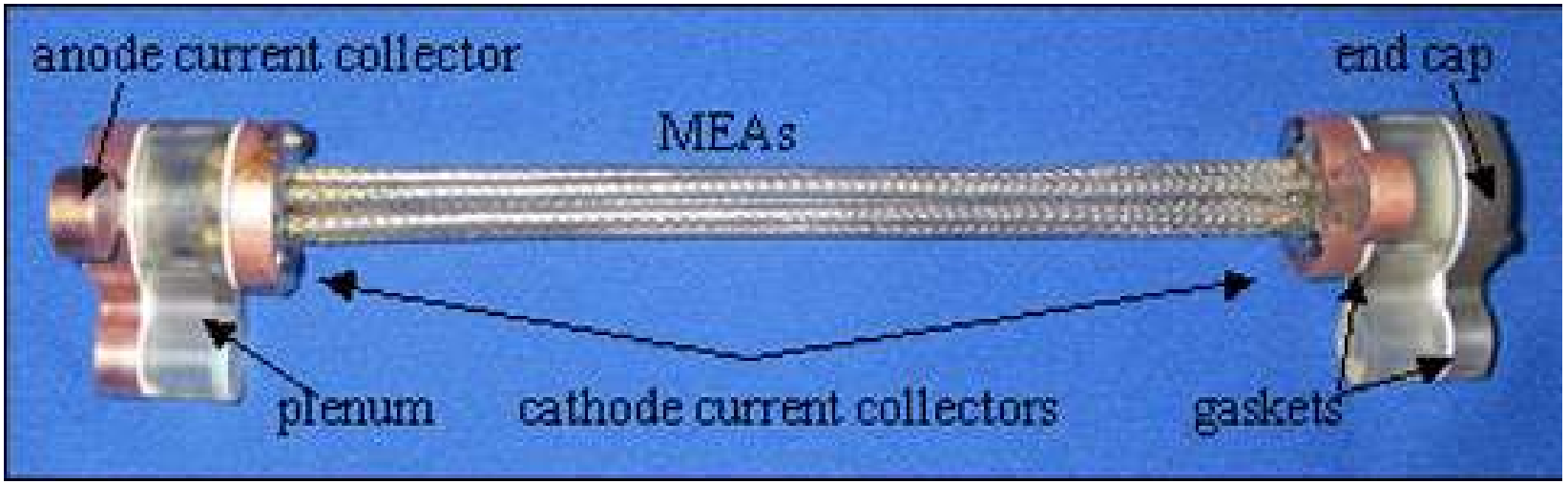
Close-Up Images of Tubular MEAs





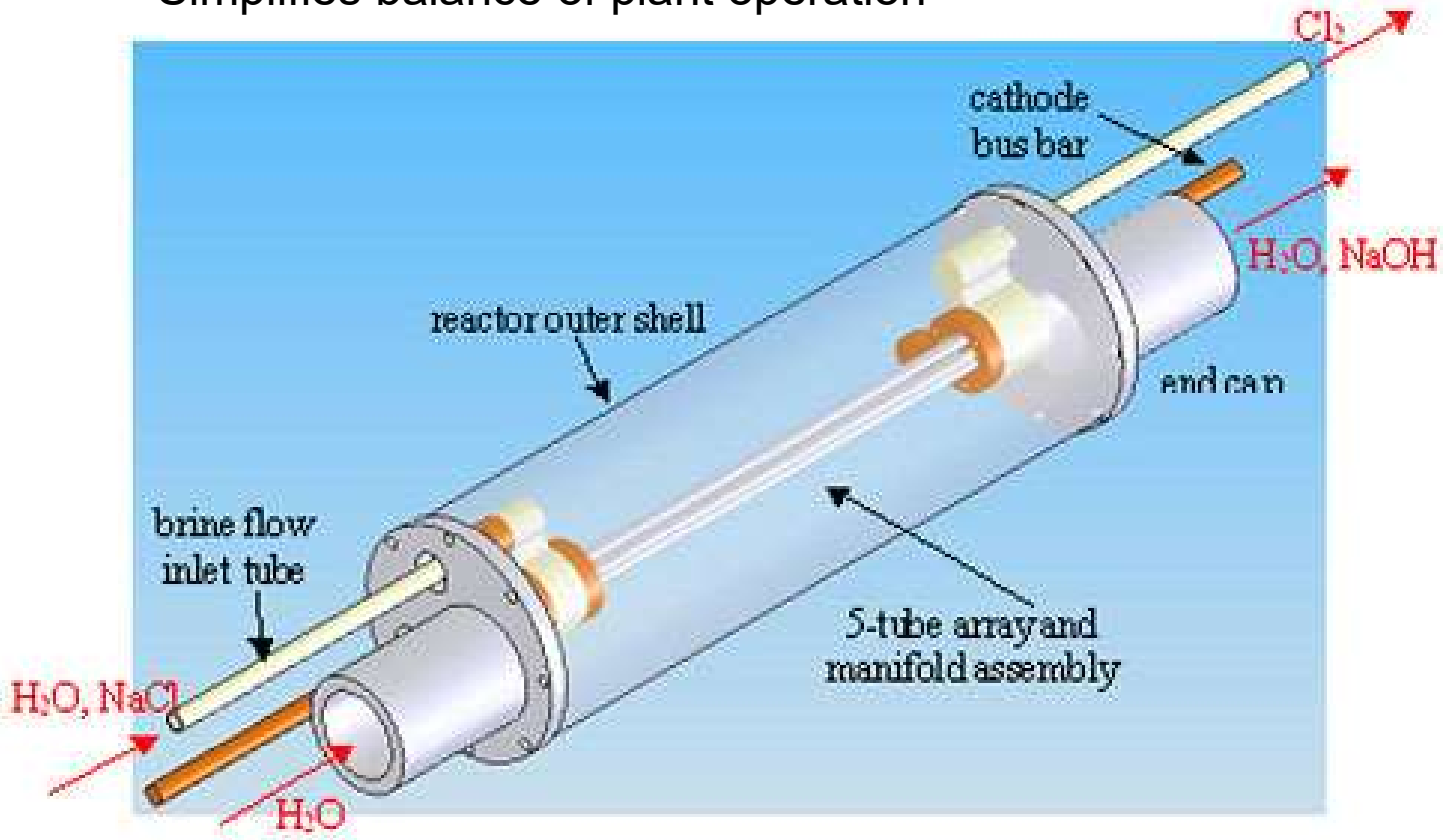
Tubular MEA Arrays Allow High Flow Rate, Low Pressure Drop Operations

- 5-tube array of MEAs connected in parallel
  - Consistent, balanced electrical and fluid flow through tubes
  - Outer braid contacts cathode current collectors
  - Inner braid contacts anode current collector
- Technology derived from our NASA high pressure electrolyzers



Innovative Tubular Electrochemical Reactor

- Flow-through design incorporates array of tubular membrane-and-electrode assemblies
  - Optimizes mixing efficiency
  - Simplifies balance of plant operation



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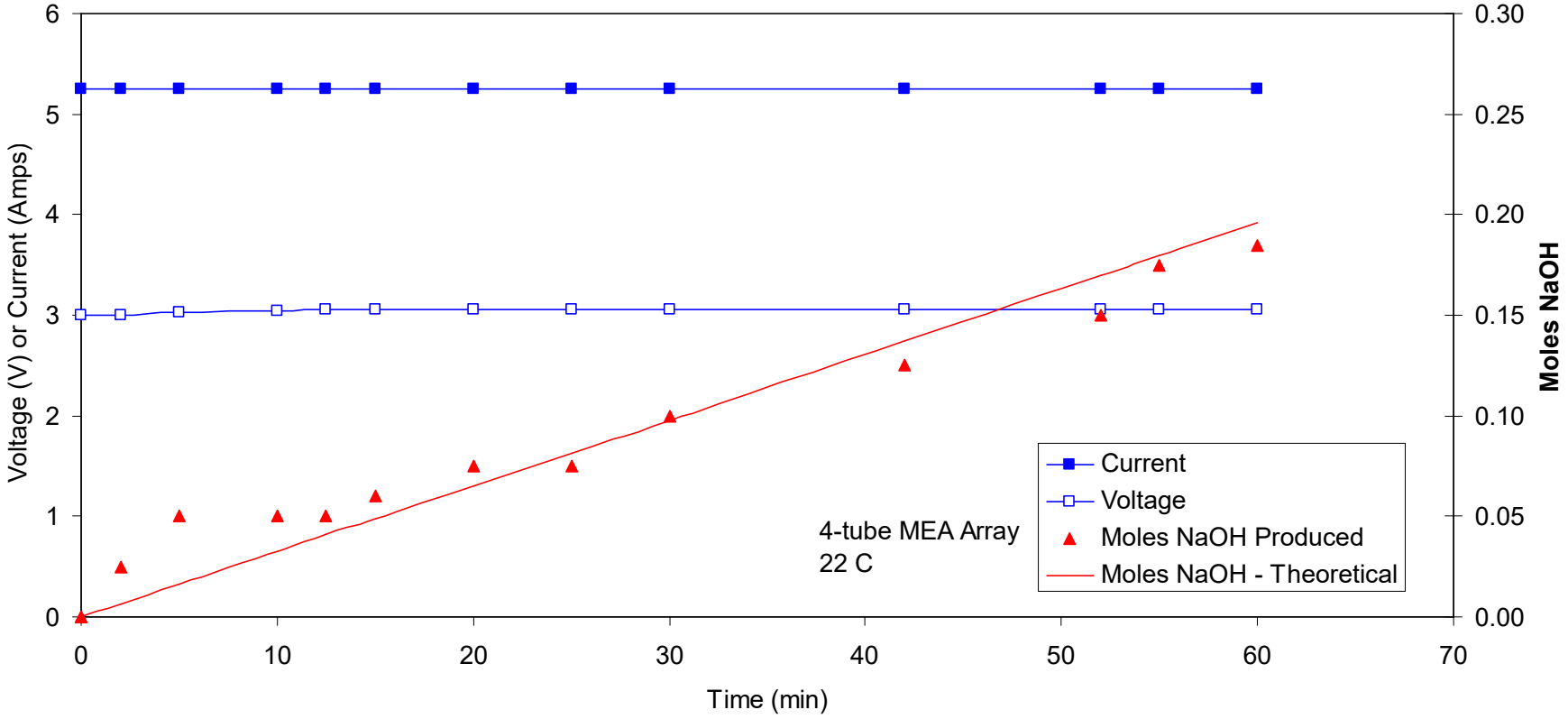
4-Tube Array Chlor-Alkali Performance Shows Stable Performance



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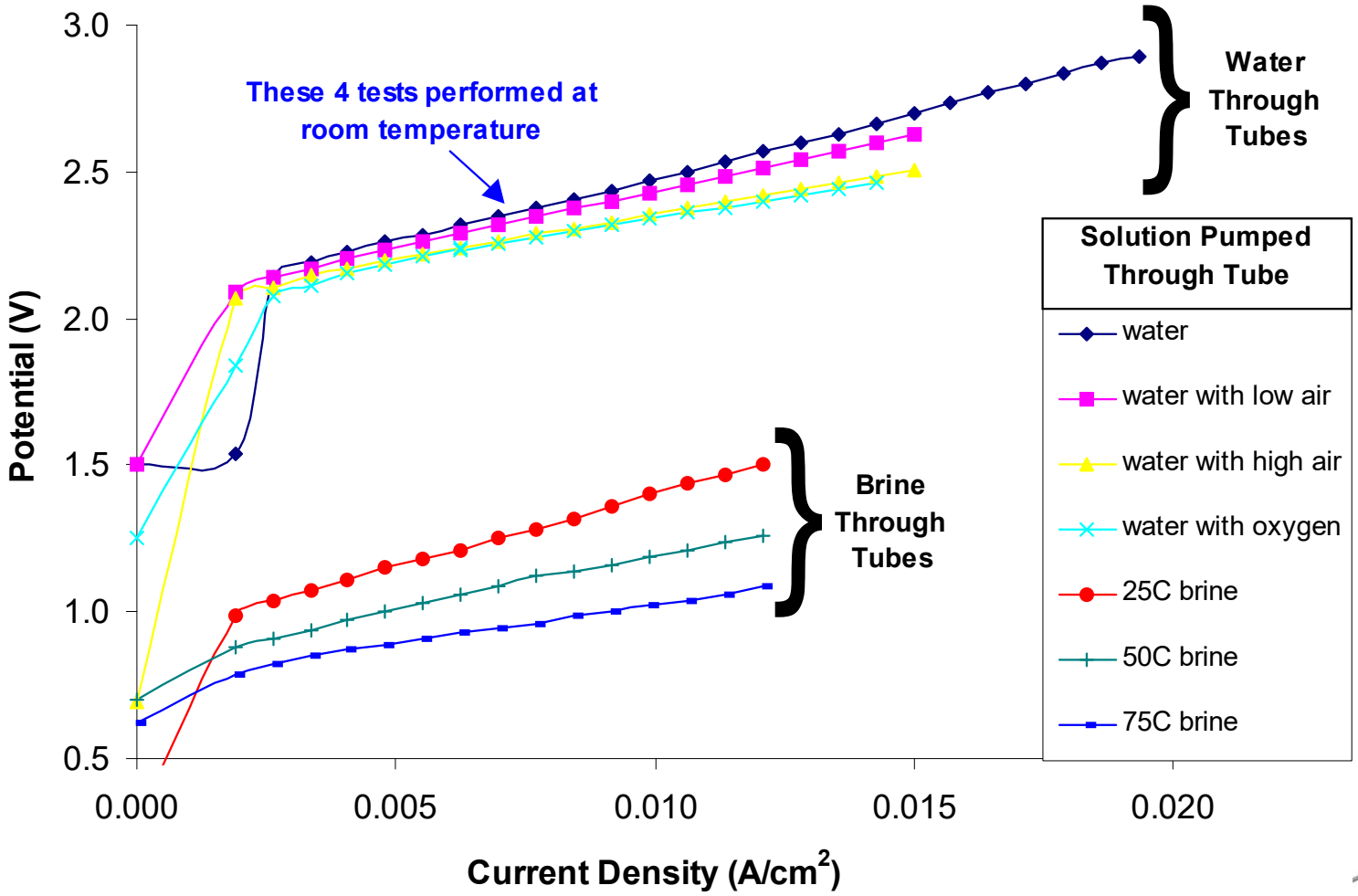
Better Air Depolarized Performance with Brine Flow Through Inner Annulus



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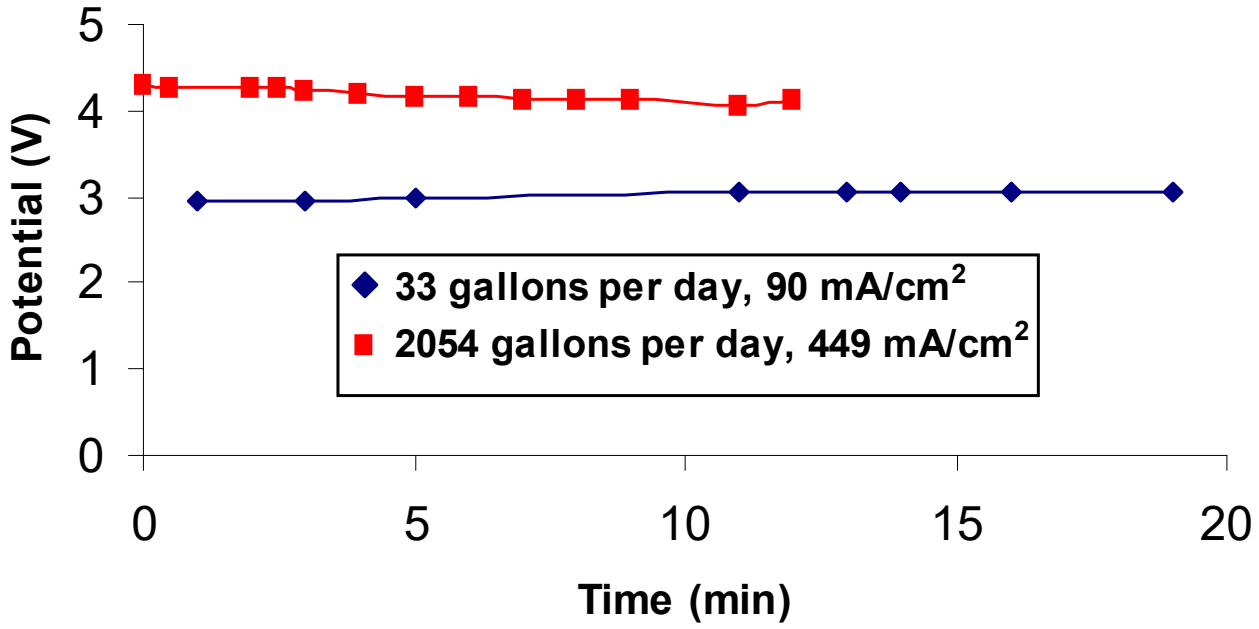
Reactor Array Performance for Producing 5 ppm Chlorine Content at Variable Water Flow Rates



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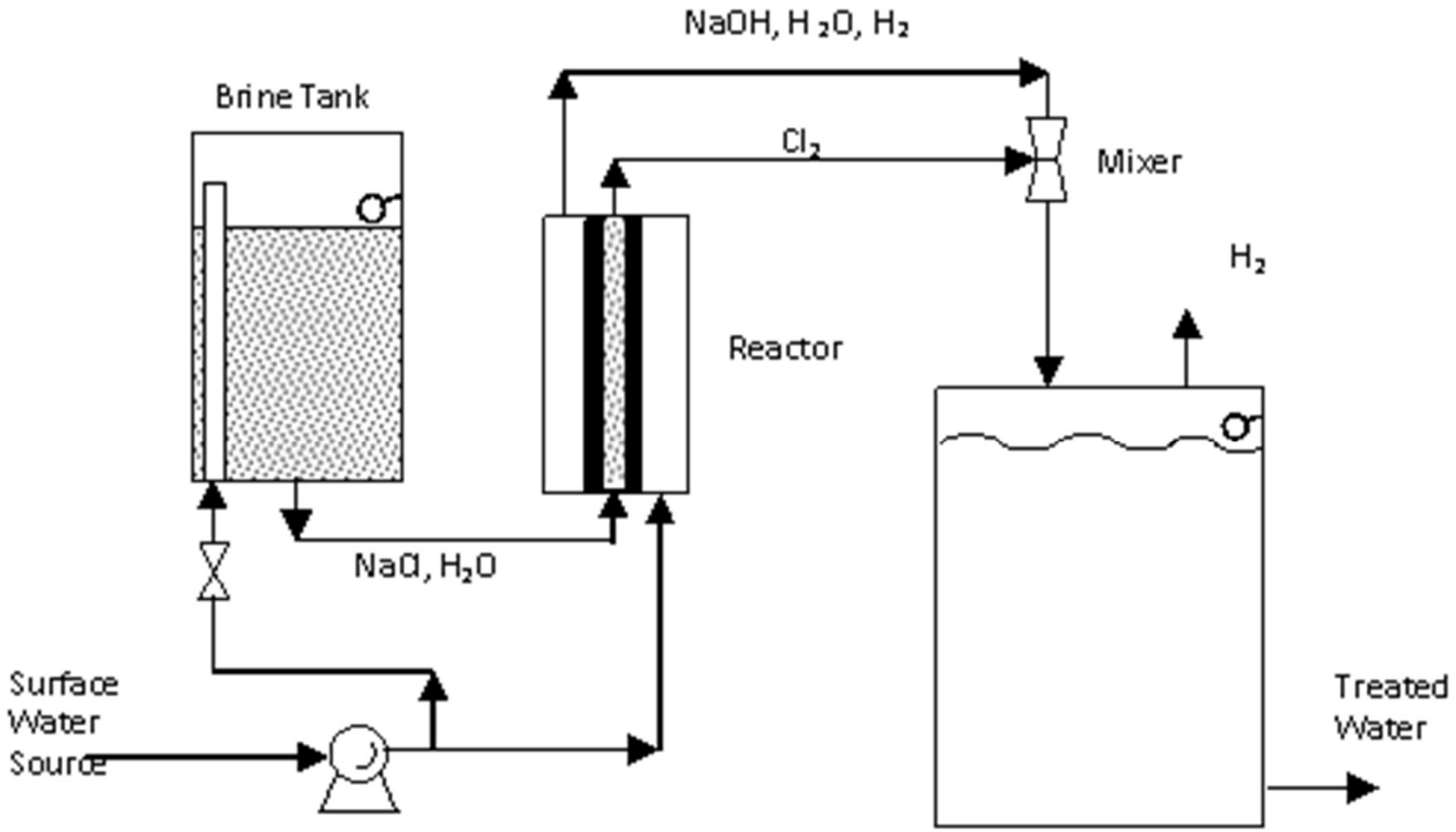
Tubular Reactor Platform Minimizes System Complexity



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Pilot-Scale System

- 35-gallon brine tank

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Capital Equipment Cost Lowered with Tubular Chlor-Alkali Reactor

- Reactor size and cost reduction over competitive on-site hypochlorite units
- Elimination of slip stream metering processes requiring few components
- Less salt carry-through with treated water allowing one-year of unattended operation

Major Components*	Cost
Brine Tank	$198
Tubular Reactor	$1000
Mixer	$40
Power Supply	$500
Tubing & Fittings	$100
Total - Approximate	$2000

* Using existing pump and holding tank

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Operating Costs for Treating 50,000 Gallons/day at a 5 ppm Chlorine Content

Component	Annual kW-hr	Annual Costs*
Pump	441 kW-hr	$66
Reactor	761 kW-hr	$114
System-Electrical	1202 kW-hr	$180
Salt	1255 (lbs)	$110
Total Yearly		$290
Average Daily Cost		$0.79

* Using $0.15/kW-hr electrical cost

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Performance Summary for an On-Site Sodium Hypochlorite Generator

- The generator is based upon a compact and efficient chlor-alkali process using an array of tubular electrochemical cells that can produce chlorine and caustic soda, and their combined product of sodium hypochlorite
  - Module designed to treat 50,000 gal/day at 5 ppm equivalent chlorine

- With this approach, we have minimized the capital and operating costs of the electrolyzer and simplified the balance of plant operation for producing a continuous stream of hypochlorite for treating surface and ground waters

- This disinfection process produces the sodium hypochlorite on-site avoiding hazardous chemical storage, minimizes the operating requirements to salt, water, and electricity, and produces a continuous and effective disinfectant for small community usage

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