조청강연

Carbon Dioxide Removal from Water

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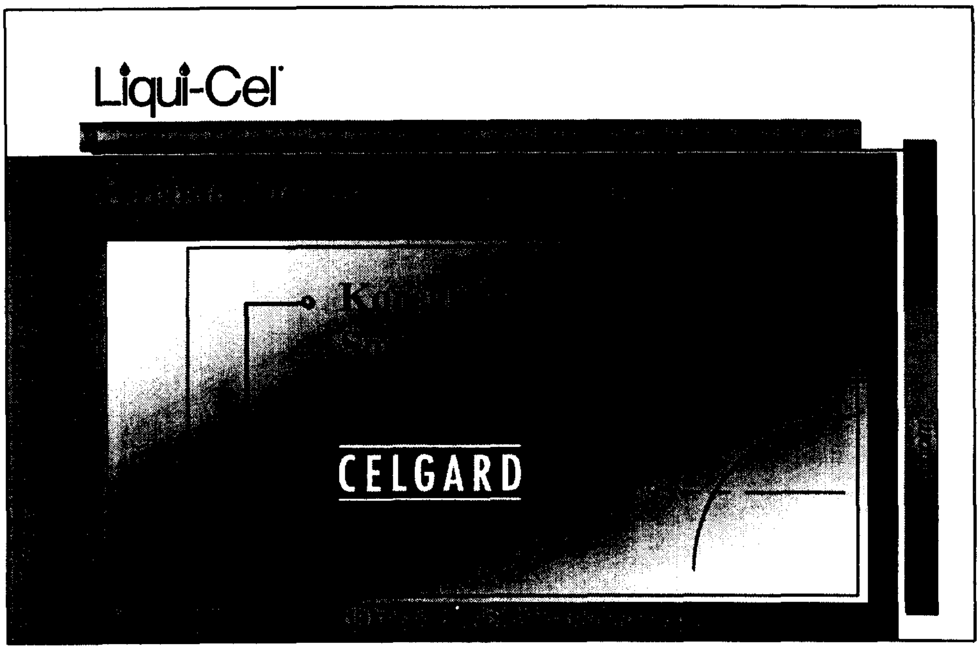
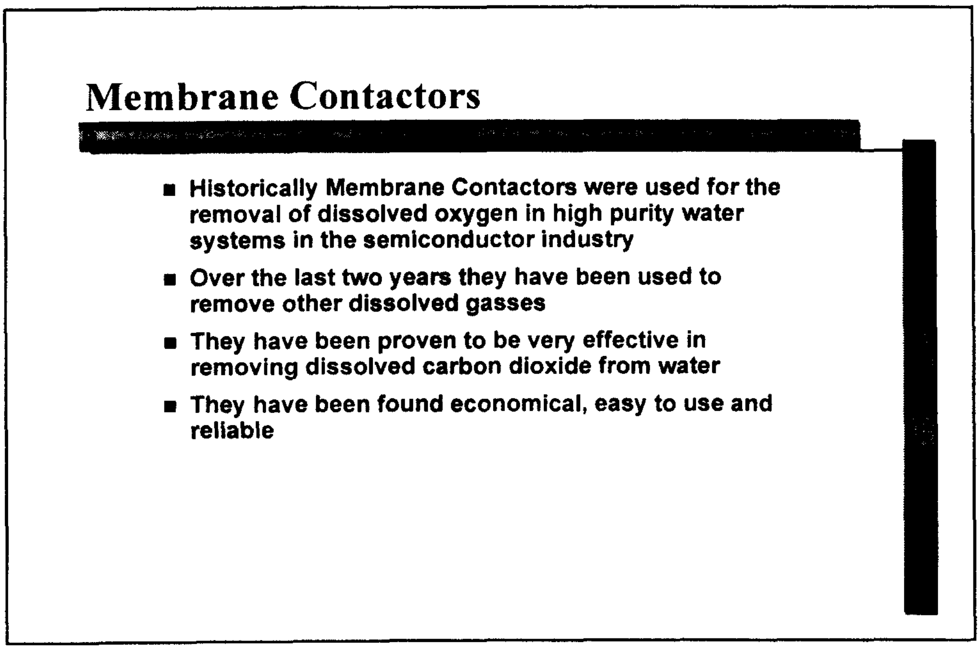


Liqui-Cel

CELGARD

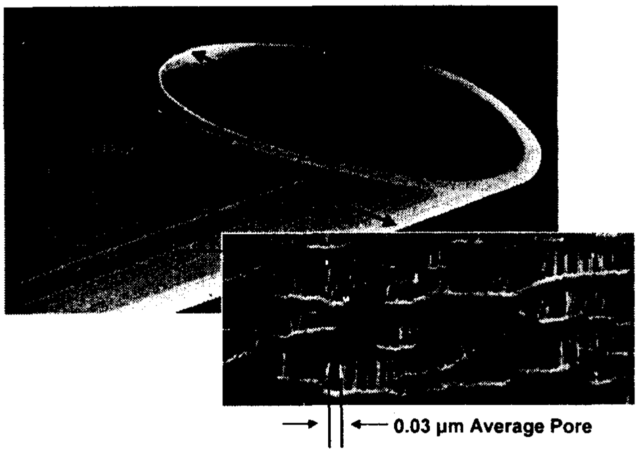


Membrane Contactors

- Historically Membrane Contactors were used for the removal of dissolved oxygen in high purity water systems in the semiconductor industry
- Over the last two years they have been used to remove other dissolved gasses
- They have been proven to be very effective in removing dissolved carbon dioxide from water
- They have been found economical, easy to use and reliable

SEM of Celgard® Microporous Hollow Fiber Membrane

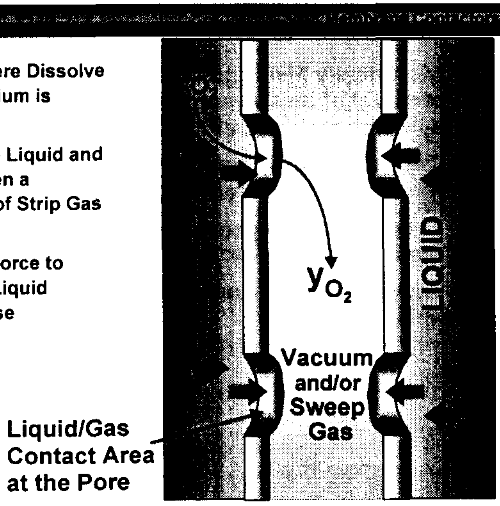
Liqui-Cel®



Principles of Gas Transfer

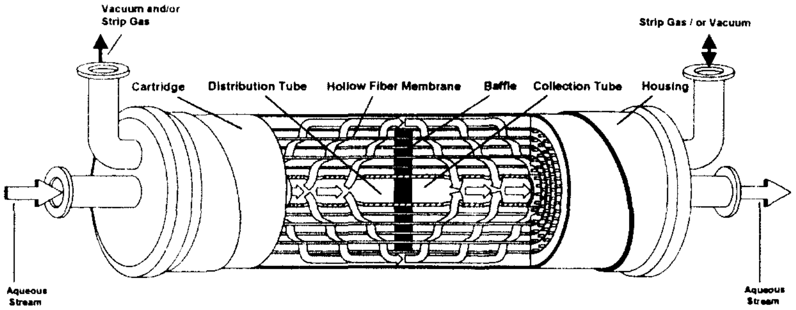
Liqui-Cel®

- Gasses in the Atmosphere Dissolve into Water until Equilibrium is Reached
- Equilibrium between the Liquid and Gas Phase Is Offset when a Vacuum and/or Source of Strip Gas is Applied
- This Creates a Driving Force to Move Gasses from the Liquid Phase into the Gas Phase



Liqui-Cel® Extra-Flow Membrane Contactor

- **Patented Design**
- **FDA Compliant***



* With Appropriate O-Rings

Chemistry of Carbon Dioxide

- **CO2 is present in water from the dissolution of minerals in water**

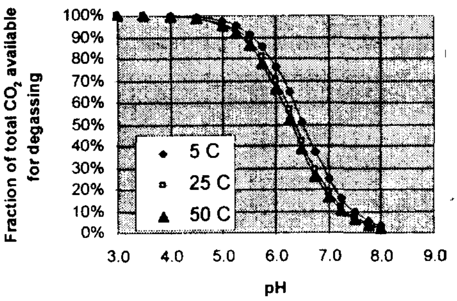
- $CO_2 + H_2O \leftrightarrow H_2CO_3$
  Carbonic acid
- $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
  Bicarbonate
- $HCO_3^- \leftrightarrow H^+ + CO_3^{-2}$
  Carbonate

Decreasing pH

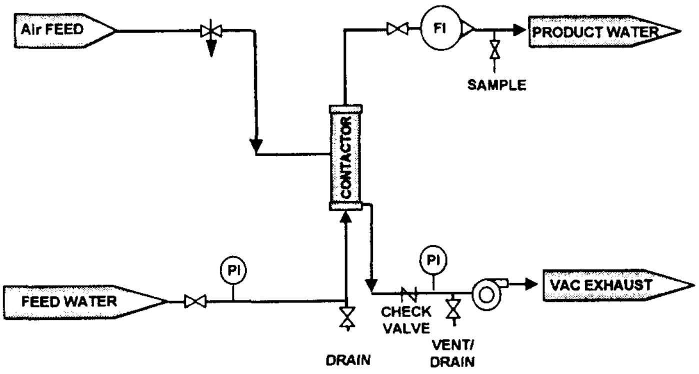
$\leftrightarrow$

Effect of pH on CO2

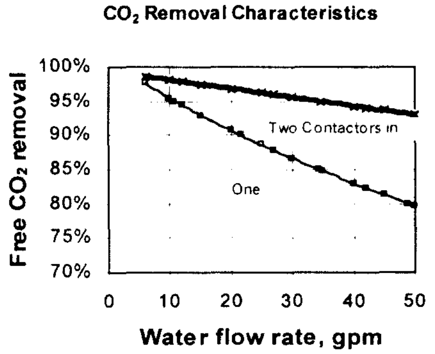
Effect of pH and Temperature on CO_2 ionization equilibrium in water



System Design



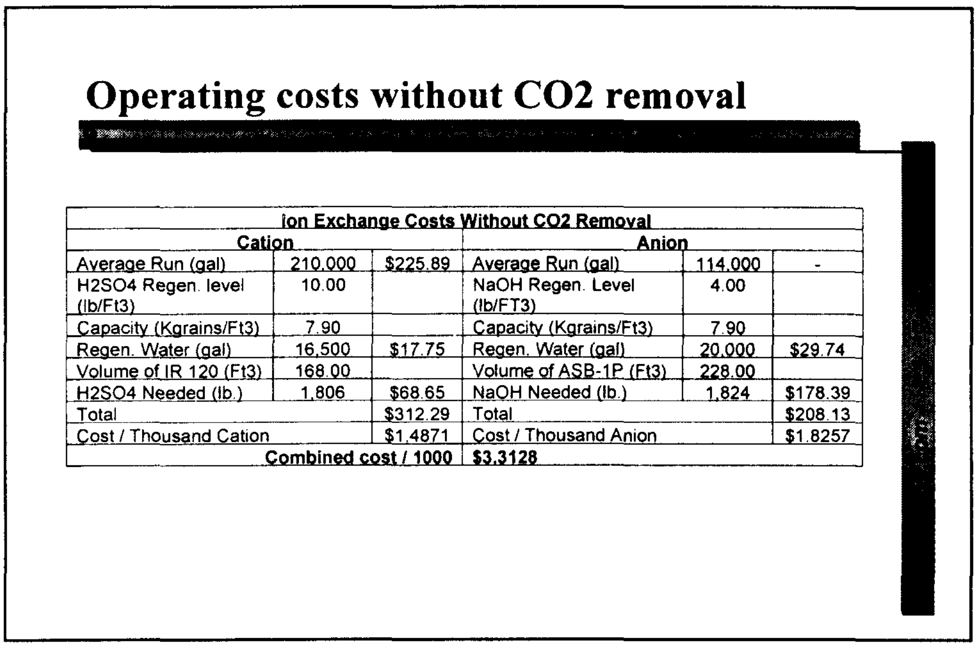
Performance Curve



Test Conditions: Air Sweep mode, G/L = 5   Temperature: 25°C

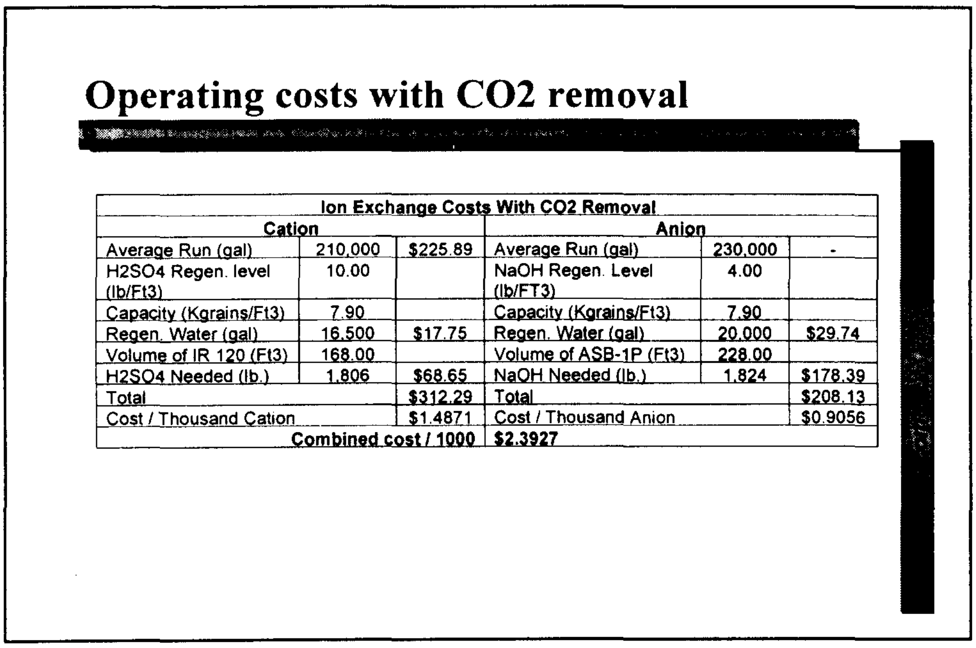
Field Study

- Municipal water
- Water flow rate 100 gpm (22.7 m3/hr)
- Water Temp 20-25C
- Location
  - Between cation and anion resin tank



Operating costs without CO_2 removal

Ion Exchange Costs Without CO_2 Removal					
Cation			Anion		
Average Run (gal)	210,000	$225.89	Average Run (gal)	114,000	-
H_2SO_4 Regen. level (lb/Ft3)	10.00		NaOH Regen. Level (lb/FT3)	4.00	
Capacity (Kgrains/Ft3)	7.90		Capacity (Kgrains/Ft3)	7.90	
Regen. Water (gal)	16,500	$17.75	Regen. Water (gal)	20,000	$29.74
Volume of IR 120 (Ft3)	168.00		Volume of ASB-1P (Ft3)	228.00	
H_2SO_4 Needed (lb.)	1,806	$68.65	NaOH Needed (lb.)	1,824	$178.39
Total		$312.29	Total		$208.13
Cost / Thousand Cation		$1.4871	Cost / Thousand Anion		$1.8257
Combined cost / 1000			$3.3128		



Operating costs with CO_2 removal

Ion Exchange Costs With CO_2 Removal					
Cation			Anion		
Average Run (gal)	210,000	$225.89	Average Run (gal)	230,000	-
H_2SO_4 Regen. level (lb/Ft3)	10.00		NaOH Regen. Level (lb/FT3)	4.00	
Capacity (Kgrains/Ft3)	7.90		Capacity (Kgrains/Ft3)	7.90	
Regen. Water (gal)	16,500	$17.75	Regen. Water (gal)	20,000	$29.74
Volume of IR 120 (Ft3)	168.00		Volume of ASB-1P (Ft3)	228.00	
H_2SO_4 Needed (lb.)	1,806	$68.65	NaOH Needed (lb.)	1,824	$178.39
Total		$312.29	Total		$208.13
Cost / Thousand Cation		$1.4871	Cost / Thousand Anion		$0.9056
Combined cost / 1000			$2.3927		

Total Cost

In this design air is being used to remove the dissolved carbon dioxide. It is drawn into the device using a vacuum pump.

The added operating cost of the vacuum pump is calculated below

Vacuum Pump Operating Costs	
Basis	80% run time Power Consumed = 3 HP * 24 * 365 * 0.8 * .7457 = 19,600 kW-hr $0.07 / kW-hr = Yearly power cost = $1372.00

Payback

Yearly Usage (gallons)	Carbonated Water	Decarbonated Water	**Savings Per Year**
12,000,000	$39,753	$ 30,084	**$9,669**

- **Compete 100 gpm (22.7 m3/hr) system with membranes, vacuum pump, piping and frame estimated cost < $12,000**

- **Payback < 1.25 years**

Features and Benefits

- **Modular.**
  - System can be shipped to customer and quickly installed
- **Low capital and operating cost**
  - Fast payback
- **Low maintenance**
  - Easy to use and does not require operator attention
- **Chemical Free operation**
  - Good for the environment - no chemical storage or handling required
- **Gas exchange takes place across the membrane**
  - No chance of gas contaminating the water
- **Responsive to flow changes**
  - System can be cycled on and off without any problems

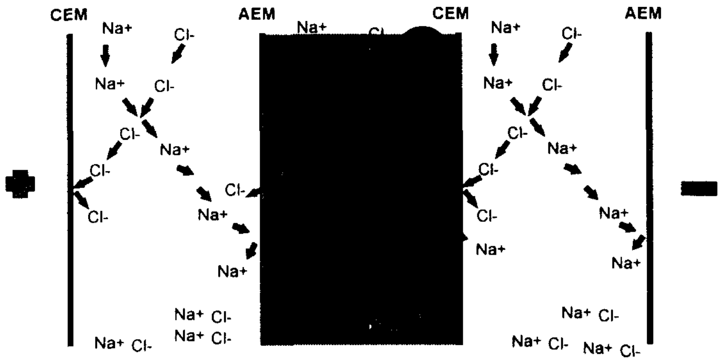
Evolution of Water System

- Pretreatment - Cation/ Anion - mixed bed
- Pretreatment - RO - Mixed Bed
- Pretreatment - RO - EDI

EDI Technology

- Uses conventional ion exchange resin sandwiched between two membranes
- Membranes are cation or anion specific
- An electrical current is applied across the sandwich
- The electrical current creates a driving forces to continuously removed from the ions from the resin.

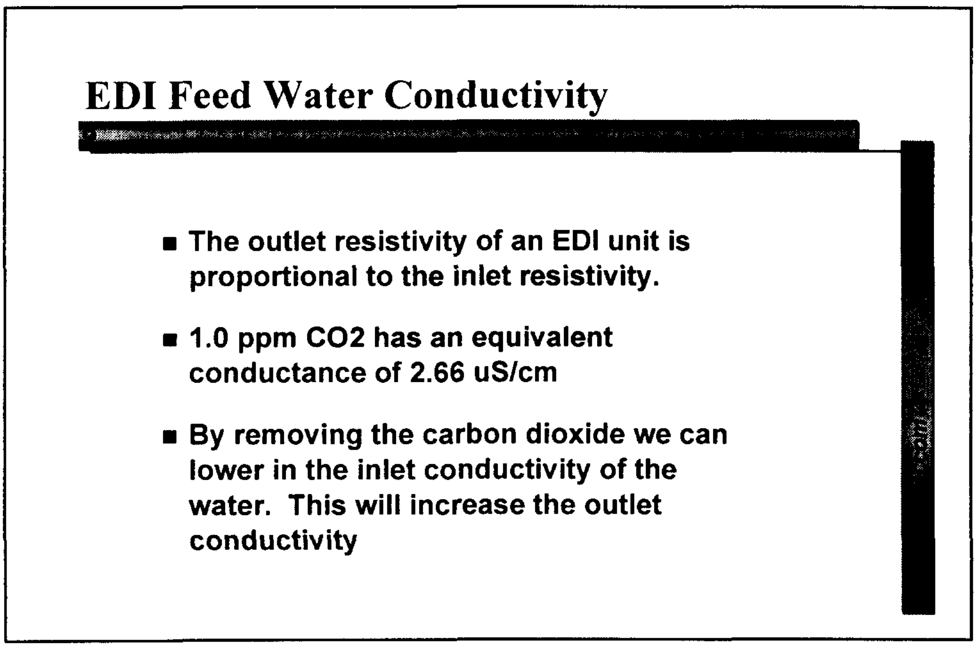
Schematic of EDI



Salt Reject

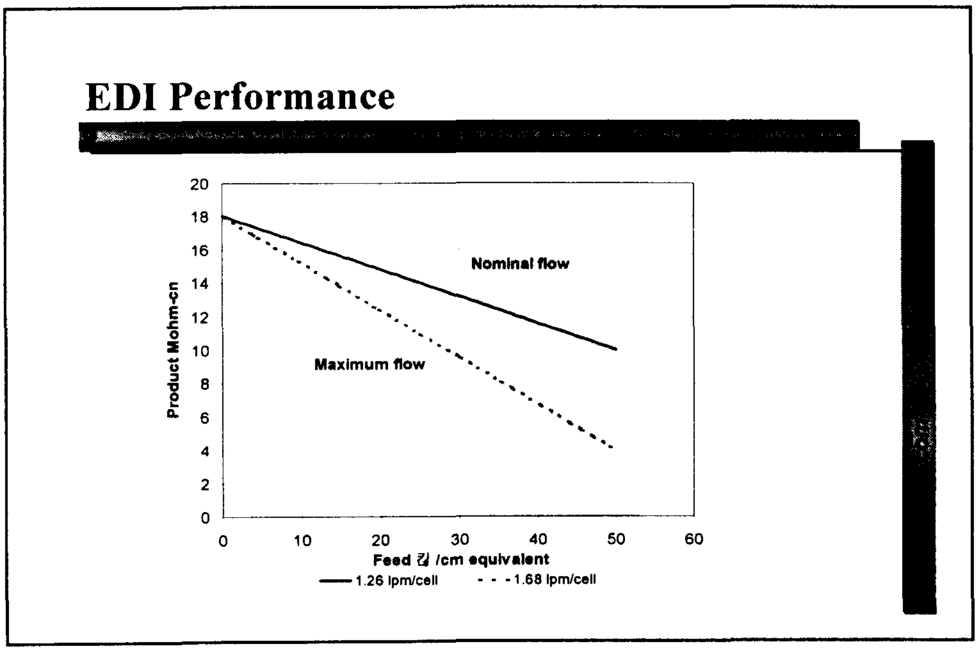
High Purity Product

Salt Reject



EDI Feed Water Conductivity

- The outlet resistivity of an EDI unit is proportional to the inlet resistivity.
- 1.0 ppm CO2 has an equivalent conductance of 2.66 uS/cm
- By removing the carbon dioxide we can lower in the inlet conductivity of the water. This will increase the outlet conductivity



EDI Performance

Conclusions

- New membranes and contactor designs have expanded the market for membrane contactors
- Membranes contactors can be used to extend the life of anion exchange resin
- membrane contactors can be used to improve the performance of EDI