Capacitive Deionization for the Removal of Total Dissolved Solids from Waste Waters: High Water Recoveries Coupled with High Ion Removal Efficiency

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One billion people worldwide do not have access to a safe water supply.

WHO statistics

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2.4 billion people do not have access to effective wastewater treatment

Worldwide, WHO statistics

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Water Issues

Possible sources of contamination:

- Nitrate
- Ammonia
- Arsenic
- Fluoride
- TDS (Salinity)
- Hardness
- Radionuclides

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Current Technologies

Contaminant	Technology
Nitrate	Biological, Ion Exchange
Ammonia	Biological
Arsenic	Absorbents
Fluoride	Membrane Systems
Salinity	Membrane Systems
Hardness	Ion Exchange
Radionuclides	Chemical Precipitation

ENPAR's ESD System treats all dissolved ions including arsenic, fluoride, hardness, metals and nitrate while maintaining *HIGH WATER RECOVERIES*.

ESD purifies water through Capacitive Deionization (CDI) using proprietary carbon electrodes.

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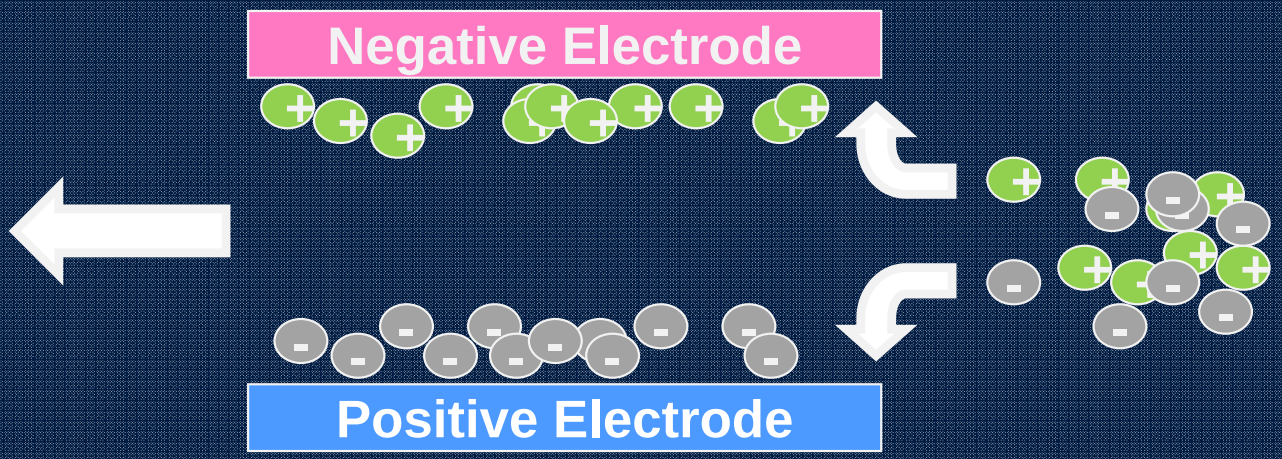
ESD System



Treated Water

@ U = 1 Volt

Contaminants:

Salts

Nitrate

Ammonia

Arsenic

Metals

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Main Advantages of ESD System

- Minimal pretreatment of the source water is required.
- No sustained concentrate leading to the formation of precipitates and fouling.
- High ion removal efficiencies coupled with extremely high water recovery rates.
- Long life cycles of the capacitor materials.

Main Advantages of ESD System

- No continual addition of salts or chemicals to treated water
- Readily removes problem contaminants such as nitrate, perchlorate, fluoride and arsenic and can be designed to remove specific monovalent ions without complete deionization of the water stream
- Can be tuned to operate at various levels of ion removal and water recovery efficiencies

ESD vs Membrane (RO)

(Comparison is for drinking water quality)

ESD	Membrane (RO)
>95% water recovery	< 70% water recovery
$0.06 per m^3	$0.08 – 0.16 per m^3
No Water Softening	Water Softening a Must
Low maintenance	High maintenance
Versatile – target problem contaminants i.e., As, NO_3	Total ion removal

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Description of Systems

Benchtop Test Station

- 0.7 m^2 total electrode surface area
- 300-400 mL/min treatment rates

Pilot Scale Systems

- 10 m^2 electrode surface area
- 2, 4 and 10 cell groups have been constructed
- Operated electrically in series and hydraulically in parallel

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Benchtop ESD 400

4-Cell ESD 9k

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Mobile Unit –South Africa/Australia

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Bench Scale Testing: TDS Removal from Process Water

- In conjunction with a Hamilton, ON steel company, water was sampled from Hamilton Harbour in western Lake Ontario
- Outlet targets: calcium and chloride concentrations to 40 mg/L and 60 mg/L respectively
- ESD system was configured to provide removal TDS of approximately 80% based on conductivity measurements

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Bench Scale Testing: TDS Removal from Process Water

Parameter (unit)	Input	Treated Water	Waste Stream
pH	7.6	6.7	8.3
Conductivity (μS/cm)	757	117	13,450
TDS (mg/L)	462	77	Approx. 8200
Na (mg/L)	66	11	2000
Ca (mg/L)	55	5.4 (90%)	208
Mg (mg/L)	15	1.6	71
Fe (mg/L)	0.37	0.12	N/A
Cl^- (mg/L)	121	21 (80%)	>3900
SO_4^{2-} (mg/L)	57	6.3	628
Water recovery of approximately 95% achieved during study			

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Bench Scale Testing: Groundwater Contaminated with Nitrate

- Groundwater contaminated with nitrate-N up to 34 mg/L and overall TDS of 790 mg/L
- Minimize overall TDS removal while reducing nitrate-N to less than 10 mg/L
- Alternate cell design was developed which targeted removal of nitrate while minimizing removal of multivalent ions
- Water recoveries of up to 95% were attained during the study
- Greater removal of monovalent ions was observed compared to multivalent ions, with excellent selectivity in removal of nitrate (69% compared to 35% removal of overall TDS)

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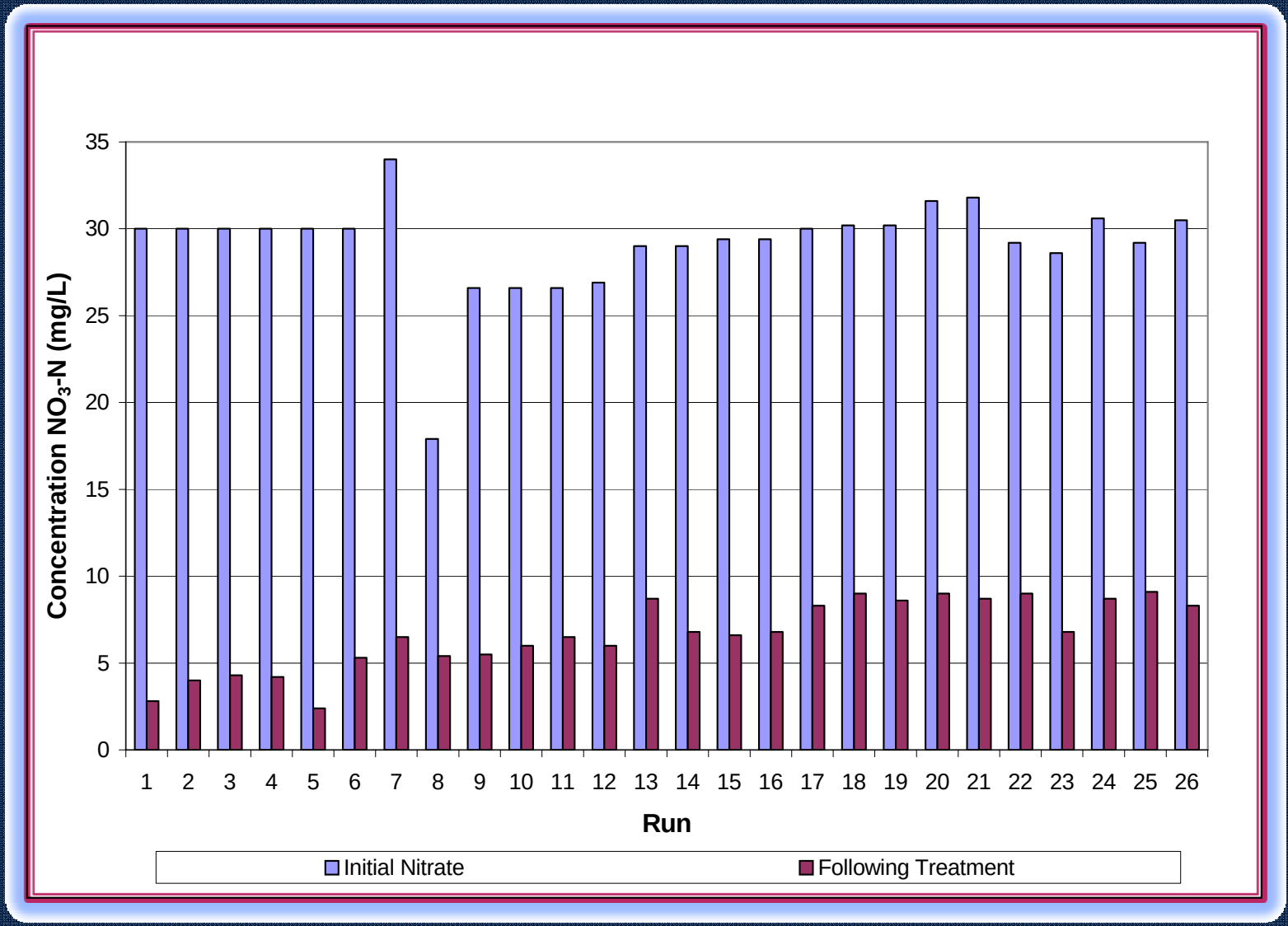
Bench Scale Testing: Groundwater Contaminated with Nitrate



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Bench Scale Testing: Groundwater Contaminated with Nitrate

Parameter (unit)	Input	Treated Water	Waste Stream
pH	8.15	7.93	7.85
Conductivity (µS/cm)	1,300	870	6,800
TDS (mg/L)	787	512	4110
Ca (mg/L)	69	68	170
Mg (mg/L)	17	17	31
Na (mg/L)	127	59	770
K (mg/L)	56	23	510
NO_3^--N (mg/L)	31	9.6	270
Cl- (mg/L)	130	72	940
SO_4^{2-} (mg/L)	130	120	270
Water Recovery		92%	

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Bench Scale Testing: Purification of High TDS Water

- Testing performed on RO waste stream samples from Middle East; conductivity 13.5 mS/cm
- Objective: highest water recovery possible, conductivity in the rage 0.6-0.8 mS/cm
- Following three purification cycles, 74% water recovery, 93% TDS removed, conductivity 0.9 mS/cm
- High water recovery achieved by recycling waste stream from third stage to purification of first stage

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Bench Scale Testing: Purification of High TDS Water

	Stage 1	Stage 2	Stage 3
Conductivity (Inlet, mS/cm)	13.48	10.11	6.33
Conductivity (Concentrate, mS/cm)	35.30	29.90	15.40
Conductivity (Treated, mS/cm)	10.11	6.33	0.927
TDS Removal (%)	25.00	37.39	85.36 (**93.12**[1])
Water Recovery (%)	86.99	85.39	68.48 (**74.29**[2])

[1]Overall removal of TDS over three stages of water treatment
[2]Overall water recovery when recycling Stage 3 waste stream into Stage 1 inlet for processing

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Pilot Testing: Removal of Arsenic from Groundwater

- ESD 5k System with a capacity of treating 5000 L/day used to examine the removal of arsenic from groundwater sources
- TDS of the groundwater, located in the town of Huautla, Mexico, was measured at 339 mg/L with an arsenic concentration of 0.210 mg/L
- In addition to testing the raw groundwater, water spiked with arsenic to a level of 0.820 mg/L was also tested
- ESD System was configured for a TDS removal of approximately 95%

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Pilot Testing: Removal of Arsenic from Groundwater

- Results of testing demonstrated consistent and effective removal of arsenic to below the detection limit (< 0.005 mg/L) when treating both raw and spiked groundwater with up to 99.4% removal efficiency
- Water recoveries of up to 97% were achieved during the trials
- Power consumption for the CDI cells was found to be 0.80 kWh/m^3 of water treated
- Total power consumption for the system, including cells, pump, and controls was measured to be 1.37 kWh/m^3 of water treated

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SUMMARY

- Currently a need for a reliable, high efficiency, low maintenance technology for the treatment of drinking water, wastewater, and industrial process water
- This technology should also be efficient at addressing problem contaminants such as arsenic and nitrate which could become a serious issue if found in high concentrations in drinking water
- We have shown that the ESD System is a promising technology for the treatment of these wastewater systems
- Compared to traditional approaches (e.g. RO), the ESD System provides high contaminant removal efficiencies while achieving high water recoveries, with minimal waste volumes

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Thank You!

Inlet Treated Waste

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