State-of-the-art Electrochemical Technologies for Industrial Water Treatment in the Kingdom of Saudi Arabia

Presented by: Dr. Gene Shelp
President & C.E.O.
ENPAR is a Canadian Company formed in 1997 that is associated with the University of Guelph. ENPAR is a “Technology Company” applying its patented and proprietary “Electrochemical Technologies” to the treatment of waste water, desalination water and drinking water contaminated by metals or nutrients, i.e., nitrate/ammonia associated with the mining, metal processing, chemical, agricultural, municipal and waste management sectors.

MIAHONA provides management and concession services for urban utilities including water supply, waste water collection and treatment facilities; EPCO/BOO/BOT basis for water and waste water treatment plants. As leading holding company, Miahona also offers urban utility engineering consultation in water and wastewater disciplines in Saudi Arabia and MENA region.
Water Issues

- Ammonia
- Arsenic
- Fluoride
- Hardness
- Metal ions
- Nitrate
- Radionuclides
- TDS (Salinity)
## Current Technologies

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate</td>
<td>Biological, Ion Exchange</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Biological</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Absorbents</td>
</tr>
<tr>
<td>Fluoride</td>
<td>Membrane Systems</td>
</tr>
<tr>
<td>Salinity</td>
<td>Membrane Systems</td>
</tr>
<tr>
<td>Hardness</td>
<td>Ion Exchange</td>
</tr>
<tr>
<td>Radionuclides</td>
<td>Chemical Precipitation</td>
</tr>
</tbody>
</table>
Capacitive Deionization

- Electrostatic removal of Total Dissolved Solids
- High ion removal efficiency
- High water recovery
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.
ESD System

Ammonia
Arsenic
Fluoride
Metal ions
Nitrate
Radionuclides

Positive Electrode

Negative Electrode

CLEAN WATER

U = 1.2 V
Operation - Purification

Contaminants

- Negative Electrode
  - U = 1.2 Volt

- Positive Electrode
Operation - Regeneration

- The polarity is reversed.
- Ions move away from the electrodes.

\[ U = 1.2 \text{ V} \]
Operation - Purge

- During the purge the ions are removed as a small volume of concentrate.
- \( U = 1.2 \text{ V} \)
Main Advantages of ESD System

• High water recoveries
• High ion removal efficiencies
• Long cycle life of capacitor materials
• No continual addition of chemicals for drinking water and brackish water applications
• Designed to target either all ions or monovalent ions (nitrate, fluoride, chloride, perchlorate, cyanide)
• Low maintenance and ease of operation
• Adjustable output water quality and recovery
ESD vs Membrane (RO)
(Comparison is for drinking water quality)

<table>
<thead>
<tr>
<th>ESD</th>
<th>Membrane (RO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;95% water recovery (WR)</td>
<td>WR 70 -75% 1&lt;sup&gt;st&lt;/sup&gt; stage</td>
</tr>
<tr>
<td></td>
<td>WR 85% 2&lt;sup&gt;nd&lt;/sup&gt; stage</td>
</tr>
<tr>
<td>$0.06 per m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>$0.08 – 0.16 per m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Water Softening</td>
<td>Water Softening</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>High maintenance</td>
</tr>
<tr>
<td>Total ion removal/mono-valent ions</td>
<td>Total ion removal</td>
</tr>
</tbody>
</table>
Heart of the ESD System – CDI Cell
4-Cell ESD 9k

Republic of Korea
Mobile Unit – South Africa/Australia

10-Cell ESD 24K
Application 1 - Recycling / Reuse

Case 1 - PUB Singapore

- Pilot testing: 2008 – 2011
  - RO reject: 2.0 - 2.7 mS/cm
  - Water recovery: 90 %
  - Ion Removal: 80 – 90 %
- Demonstration plant
  - 150 m³ / day
- Full scale: 5000 m³ / day

2-Cell ESD 5K
Application 1 - Recycling / Reuse

Case 2 - RO Reject Project 2010

- RO reject
- Conductivity: 13.5 mS / cm
- Treated water: 0.9 mS / cm
- Water recovery: 66.42%

- Brackish groundwater
- Conductivity: 3.21 mS / cm
- Ion Removal: 74%
- Water recovery: >91%
### Application 1 – Recycling / Recycling

#### Case 2 continued - RO Concentrate

<table>
<thead>
<tr>
<th></th>
<th>Inlet</th>
<th>Concentrate</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mS/cm</strong></td>
<td>13.48</td>
<td>35.30</td>
<td>10.11</td>
</tr>
<tr>
<td><strong>mS/cm</strong></td>
<td>10.11</td>
<td>29.90</td>
<td>6.33</td>
</tr>
<tr>
<td><strong>mS/cm</strong></td>
<td>6.33</td>
<td>15.40</td>
<td>0.927</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDS Removal (%)</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>%</strong></td>
<td>25.00</td>
<td>37.39</td>
<td>85.36 (93.12&lt;sup&gt;1&lt;/sup&gt;)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Recovery (%)</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>%</strong></td>
<td>86.99</td>
<td>85.39</td>
<td>68.48 (66.42&lt;sup&gt;2&lt;/sup&gt;)</td>
</tr>
</tbody>
</table>

<sup>1</sup> Overall removal of TDS over three stages of water treatment

<sup>2</sup> Overall water recovery when recycling Stage 3 waste stream into Stage 1 inlet for processing
Application 2 – Stand Alone System

Case 1 - Ground Water Nitrate Treatment

- Groundwater (Guelph Ontario)
  - Nitrate-N of 34 mg/L
  - TDS of 790 mg/L
- All ion design – treated water
  - < 10 mg nitrate-N /L
  - 70% removal of TDS
  - Water recoveries - 95%
- Mono-valent design – selective removal of monovalent ions
  - 69% removal of nitrate
  - 35% removal of overall TDS
  - Lower power requirements
## Application 2 – Stand Alone System

### Case 1 - Mono-valent Design – Nitrate in Groundwater

<table>
<thead>
<tr>
<th>Parameter (unit)</th>
<th>Input</th>
<th>Treated Water</th>
<th>Waste Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.15</td>
<td>7.93</td>
<td>7.85</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>1,300</td>
<td>870</td>
<td>6,800</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>787</td>
<td>512</td>
<td>4110</td>
</tr>
<tr>
<td>Ca (mg/L)</td>
<td>69</td>
<td>68</td>
<td>170</td>
</tr>
<tr>
<td>Mg (mg/L)</td>
<td>17</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Na (mg/L)</td>
<td>127</td>
<td>59</td>
<td>770</td>
</tr>
<tr>
<td>K (mg/L)</td>
<td>56</td>
<td>23</td>
<td>510</td>
</tr>
<tr>
<td>NO$_3^-$-N (mg/L)</td>
<td>31</td>
<td>9.6</td>
<td>270</td>
</tr>
<tr>
<td>Cl- (mg/L)</td>
<td>130</td>
<td>72</td>
<td>940</td>
</tr>
<tr>
<td>SO$_4^{2-}$ (mg/L)</td>
<td>130</td>
<td>120</td>
<td>270</td>
</tr>
<tr>
<td>Water Recovery</td>
<td></td>
<td></td>
<td>92%</td>
</tr>
</tbody>
</table>
Application 2 – Stand Alone System

Case 2 - Ground Water Arsenic Treatment

Huautla, Mexico - Collaboration with Government of Mexico
- ground water arsenic of 0.210 mg/L
- spiked ground water of 0.820 mg/L
- TDS of 339 mg/L

Results:
- < 0.005 mg As/L for both raw and spiked groundwater
- 99.4% removal efficiency
- water recovery - 97 %
- CDI cells - 0.80 kWh/m³
- total power consumption - 1.37 kWh/m³
Summary

• ESD is a proven reliable, high efficiency and low maintenance treatment system
• Applicable to the treatment of drinking water, wastewater and industrial process water
• High removal efficiencies with high water recoveries and minimal waste volumes
• Enhances efficiency of existing conventional RO systems
• Effective approach for drinking water issues, i.e., nitrate and arsenic
AmmEL-LC and AmmEL-HC

Patented AmmEL Processes for the Treatment of Ammonia in Municipal and Industrial Wastewater

Ammonia Converted to Environmentally–Friendly Nitrogen Gas
Introduction

• Ammonia listed as a toxic substance by Environment Canada

• One approach in the mining industry has been to lower the pH of the effluent to render it less toxic by shifting the NH$_3$/NH$_4^+$ equilibrium

• While this approach has assisted in meeting acute lethality discharge requirements, the total ammonia-N released into the environment is not reduced

• Current technology for treating ammonia relies heavily on biological activity (e.g. nitrification) to convert ammonia to nitrate
Introduction

• Total nitrogen removal requires additional biological processes to remove nitrate from wastewater prior to discharge
• Biological treatment systems are adversely affected by cold temperatures and changes in effluent composition
• A novel and patented ion-exchange/electrochemical treatment technology (the AmmEL system) has been developed by Enpar Technologies, Inc. which is not adversely affected by low temperature
The AmmEL-LC Process

Loading (Phase 1)

Wastewater (NH₄)

Treated Effluent

Regeneration (Phase 2)

NH₄

Conversion (Phase 3)

NH₄

N₂

Electrochemical Reactor

Regenerant Tank
The AmmEL Advantage

• Eliminates nitrogen loading by converting ammonia directly into innocuous $N_2$
• Does not produce nitrate and the GHG nitrous oxide associated with biological treatment
• Not affected by high calcium conditions
• Intermittent operation - no start-up delays
• Can be fully automated - low maintenance
System Applications

- Mining effluent or process streams containing ammonia derived from the use of ammonia based blasting powder and/or the oxidation of cyanide
- Tertiary treatment for municipal waste water treatment plants (MWTP) and lagoon systems
- Process streams related to steel, fertilizer and chemical industries
Pilot Study

The *AmmEL-LC* System
AmmEL-LC Pilot Unit Specifications

- 3-20 cm x 3.05m fluidized bed IX columns, BV = 59.3L in a lead/lag arrangement
- 1.5 kW electrochemical reactor
- Main operating conditions:
  - Wastewater flow rate: 18-20 L/min
  - Recharge brine flow rate: 8-10 L/min
  - Brine NaCl concentration: 3-4%
  - Cell current: 150 A
Typical Series Column Results

Ammonia Loading, Columns C1 & C3

![Graph showing Ammonia Concentration (mg/L) and Ammonia Removed (%) over Time (h).]
## Series Column Results

<table>
<thead>
<tr>
<th></th>
<th>C₂ &amp; C₁</th>
<th>C₁ &amp; C₃</th>
<th>C₃ &amp; C₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate (L/min)</td>
<td>18.2</td>
<td>18.1</td>
<td>18.3</td>
</tr>
<tr>
<td>Total Run Time (h)</td>
<td>16</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Water Temperature (°C)</td>
<td>5.9</td>
<td>6.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Inlet pH</td>
<td>7.79</td>
<td>7.84</td>
<td>7.82</td>
</tr>
<tr>
<td>Outlet pH</td>
<td>7.86</td>
<td>7.86</td>
<td>7.91</td>
</tr>
<tr>
<td>Average Inlet NH₃ (mg/L)</td>
<td>23.0</td>
<td>31.0</td>
<td>35.3</td>
</tr>
<tr>
<td>Average Outlet NH₃ (mg/L)</td>
<td>4.0</td>
<td>3.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>
The system is designed to treat 400 $m^3$ of mine waste per day containing an average of 30 mg of ammonia-nitrogen/L. Emission levels are 10 mg NH$_3$-N/L. Three zeolite filled 30 cm (i.d.) x 6 m ion exchange columns. Electrochemical reactor $\rightarrow$ 18 $m^2$ of anode surface area; 16V, 2000A DC rectifier. Chlorine gas scrubber to comply with Ontario MOE chlorine emission levels.
Ion Exchange Columns
Electrochemical Reactor
AmmEL vs Biological

AmmEL:
- Ammonia is converted to nitrogen gas
- No GHG, Nitrate
- Complete solution
- Small footprint
- $1.6 M (1MLPD)

Biological:
- Ammonia is converted to nitrate (carcinogen)
- Creates GHG
- Partial solution
- Large footprint
- $1.7 – $2.5 M (1MLPD)
The AmmEL-HC System (SS Version)

Electrochemical / Strip & Scrub Method for the Treatment of Water Containing Higher Ammonia Concentrations
The AmmEL-HC System

Stripping (Phase 1)

Wastewater (NH₄)

Air

Air + NH₃

Treated Effluent

Scrubbing (Phase 2)

Scrubbing Liquid

NH₄

Conversion (Phase 3)

NH₄

N₂

Electrochemical Reactor
The AmmEL-HC System
(City of Edmonton Pilot Unit)
Thank You