Advanced Integrated Technologies for Treatment and Reutilization of Impaired Water in Fossil Fuel-Based Power Plant Systems

David Ogden, Dora Lopez, Xiujuan Chen, Xingbo Liu and Jason Trembly

Thursday March 23, 2017

Institute for Sustainable Energy and the Environment

RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY

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OHIO UNIVERSITY

ISEE Overview

Institute Facts

- Faculty: 3
- Staff: 4 (Engineers and scientists)
- Students: 16 GS; 14 UG
- Space: 14,000 ft^2
- Over $16M in external research since 2008

Research Capabilities

- Thermocatalytic Processes
- Process Engineering & Design
- Process Modeling & Simulation

Home to Two Ohio Third Frontier Innovation Platform Programs

Water
- Brine treatment
- Nutrient recovery
- NORM capture

Coal
- Coal conversion (syngas & pyrolysis)
- Coal liquefaction
- Composite materials

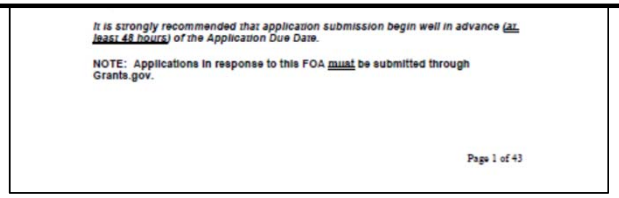
Oil & Gas
- Reinjection & reservoir scaling studies
- Reservoir nanofracturing and modeling
- Modular alkanes separations

Biomass
- Algae growth & conversion
- Thermocatalytic conversion
- Biochemicals production

Project Specifics and Team

OHIO Project Team

- **Project Management**
  - Jason Trembly, Ph.D. (OHIO)
- **Process Development**
  - Xingbo Liu, Ph.D. (WVU)
  - David Ogden (OHIO)
  - Graduate Student(s)
- **Process Modeling**
  - Dora Lopez, Ph.D. (OHIO)


It is strongly recommended that application submission begin well in advance (at least 48 hours) of the Application Due Date.

NOTE: Applications in response to this FOA must be submitted through Grants.gov.

Page 1 of 43

Project Specifics

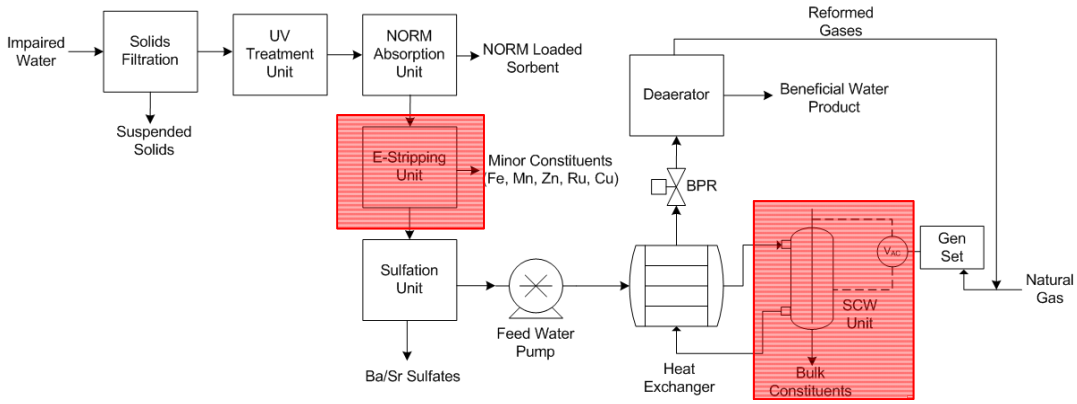
- DOE/NETL Cooperative Agreement No. DE-FE0026315
- DOE Project Manager: Barbara Carney
- Principal Investigator: Jason Trembly

Period of Performance

- September 1, 2015 to August 30, 2017

Brine Treatment Process

- **Technologies**
  - UV Treatment
  - NORM Adsorption (Produced water)
  - Electrochemical Removal
    - Minor constituent removal (Fe^{2+}/Fe^{3+}, Mn^{2+}, Ru^{2+}, Zn^{2+}, and Cu^{2+})
  - Selective precipitations
    - Minor constituents (Ba^{2+} and Sr^{2+})
  - SCW Treatment
    - Bulk constituents



Brine Treatment Process

Project Objectives

Overall

- Develop a site deployable cost-effective technology for treating brine generated from CO_2 storage operations

Small Scale Testing

- Validate technical and commercial feasibility of new internally heated SCW treatment methodology for removal of major constituents from impaired water
- Determine effectiveness of electrochemical stripping to remove minor constituents from impaired water
- Determine effectiveness of corrosion resistant coatings to improve SS performance in high chloride content water

Process Engineering

- Identify process configurations which maximize constituent removal, optimize heat integration, and minimize water treatment costs

Selective Ion Removal

Energy Consumption of Electro-Coagulation for Zn-ion Removal

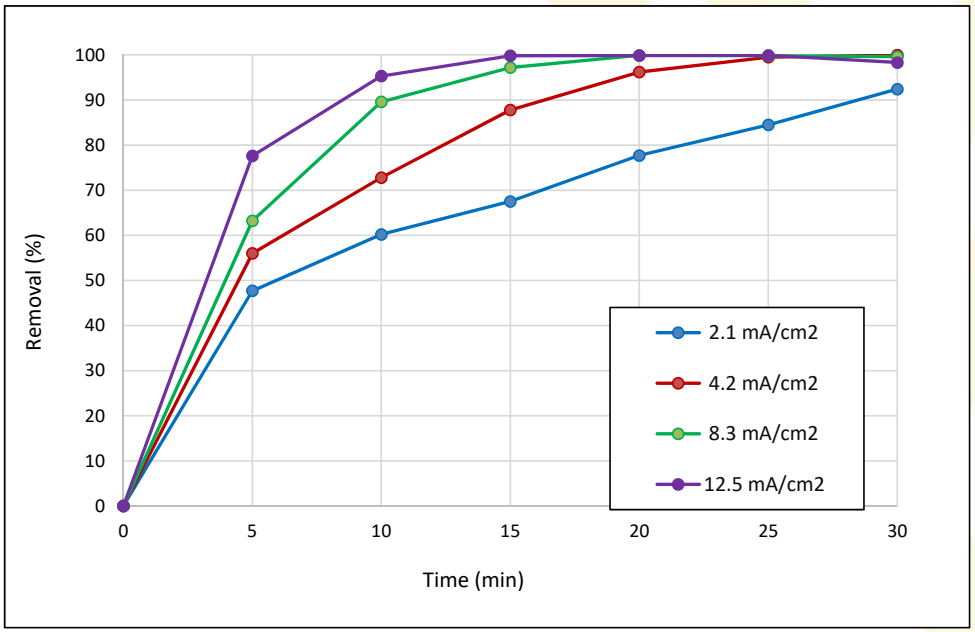


Fig. 1 Evolution of zinc removal efficiency versus EC time at different current densities. C_0 = 50 mg/L.

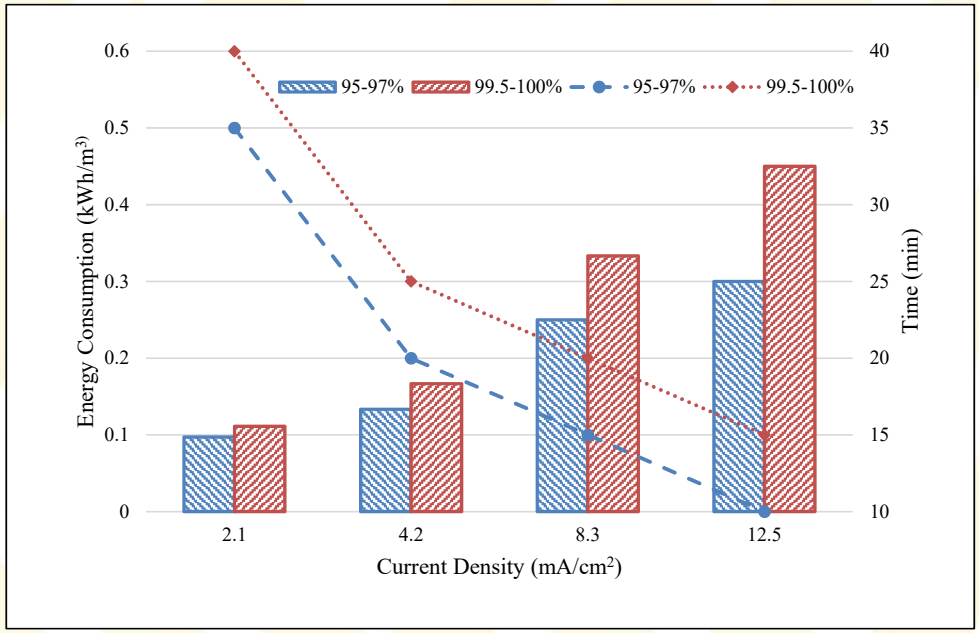


Fig. 2 Variation of energy consumption (bar) and required EC time (line) as a function of current densities for removal efficiency of 96% and 99%.

Removal of Metal Ions from Multi-Ion Solution

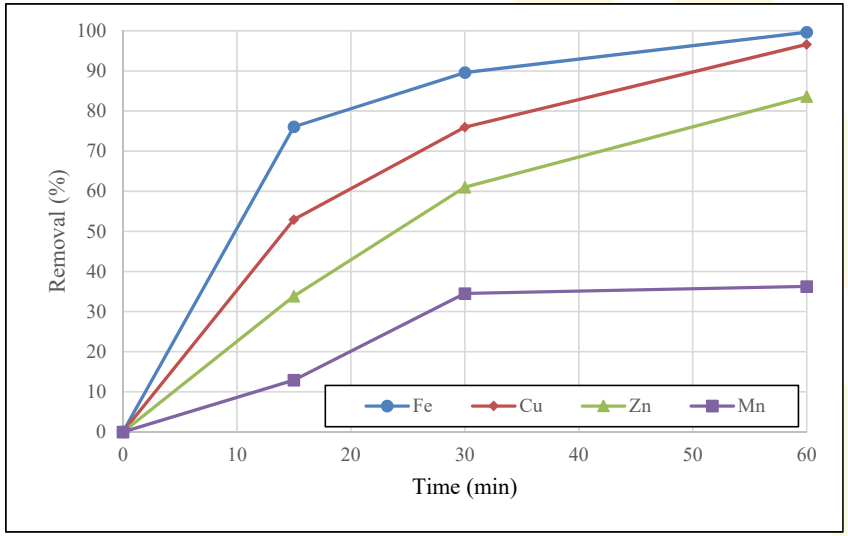


Fig. 3 Evolution of heavy metal ions removal efficiency versus EC time. Initial concentration of Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} = 25 mg/L in mixed solution.

- Competitive removal of Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} in the mixed solution.
- Removal rate of Zn^{2+} is almost two times slower than of Fe^{3+}, and half times slower than Cu^{2+} during a short EC time, but it tends to similar removal efficiency as increasing of duration time.

Typically, previous work focused on the zinc removal by EC.

What makes the different removal behavior of Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} ?

Removal of Metal Ions from Produced Water

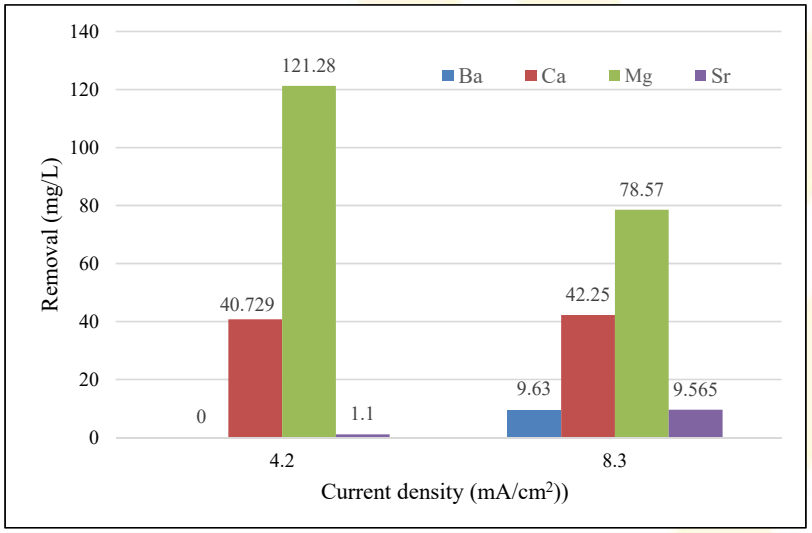


Fig. 4 Evolution of metal ions removal versus EC time at different current densities. mixed solution: t = 30 min
C_{Ba} = 249.15 mg/L, C_{Ca} = 729.73 mg/L
C_{Mg} = 316.07 mg/L, C_{Sr} = 1760.22 mg/L

Remove rate: Mg > Ca > Sr > Ba

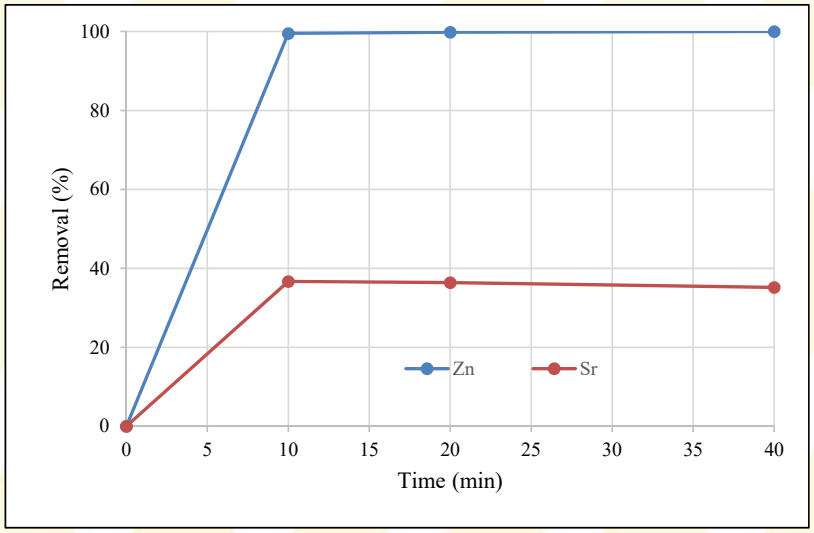


Fig. 5 Evolution of heavy metal ions removal efficiency versus EC time. Initial concentration of Zn^{2+} and Sr^{2+} = 10 mg/L in mixed solution, current density is 4.2 mA/cm².

Remove rate: Zn >> Sr

Possible Removal Mechanisms: co-precipitation, precipitation as hydroxide forms

Ionic solid	K_{sp} (at 25°C)
$Fe(OH)_3$	4.0×10^{-38}
$Al(OH)_3$	2.0×10^{-32}
$Cu(OH)_2$	1.6×10^{-19}
$Zn(OH)_2$	4.5×10^{-17}
$Mn(OH)_2$	2.0×10^{-13}
$Mg(OH)_2$	8.9×10^{-12}
$Ca(OH)_2$	1.3×10^{-6}
$Sr(OH)_2$	3.2×10^{-4}
$Ba(OH)_2$	5.0×10^{-3}

- The differences of removal behavior between Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} could be attributed to the co-presence of different removal mechanisms.
  - Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} compete for hydroxide ions produced at the cathode. → Precipitation as hydroxide forms
  - Fe^{3+}, Cu^{2+}, Zn^{2+} and Mn^{2+} compete for sorption sites at the aluminum hydroxide surface → Coprecipitation: adsorbed by $Al(OH)_3$ coagulant
  - Co-precipitation of Cu^{2+}, Zn^{2+} and Mn^{2+} at iron hydroxide surface, or $Cu(OH)_2$ and $Zn(OH)_2$ surface → Attributed to increase of removal efficiency

Brine Joule Treatment

Experimental Setup

- Design Specifications
  - Pressure: 310 bar (4,641 psi)
  - Temperature: 525 °C
  - Material of Construction: Hastelloy C-276
  - Feed Rate: 0-300 mL/min
- Safety Measures
  - Pressure relief valves (3) and rupture discs (3)
  - Interlocked control system monitoring system temperature, pressure, and current
- Advantages
  - Cooler/thinner reactor wall
  - High throughput/small footprint

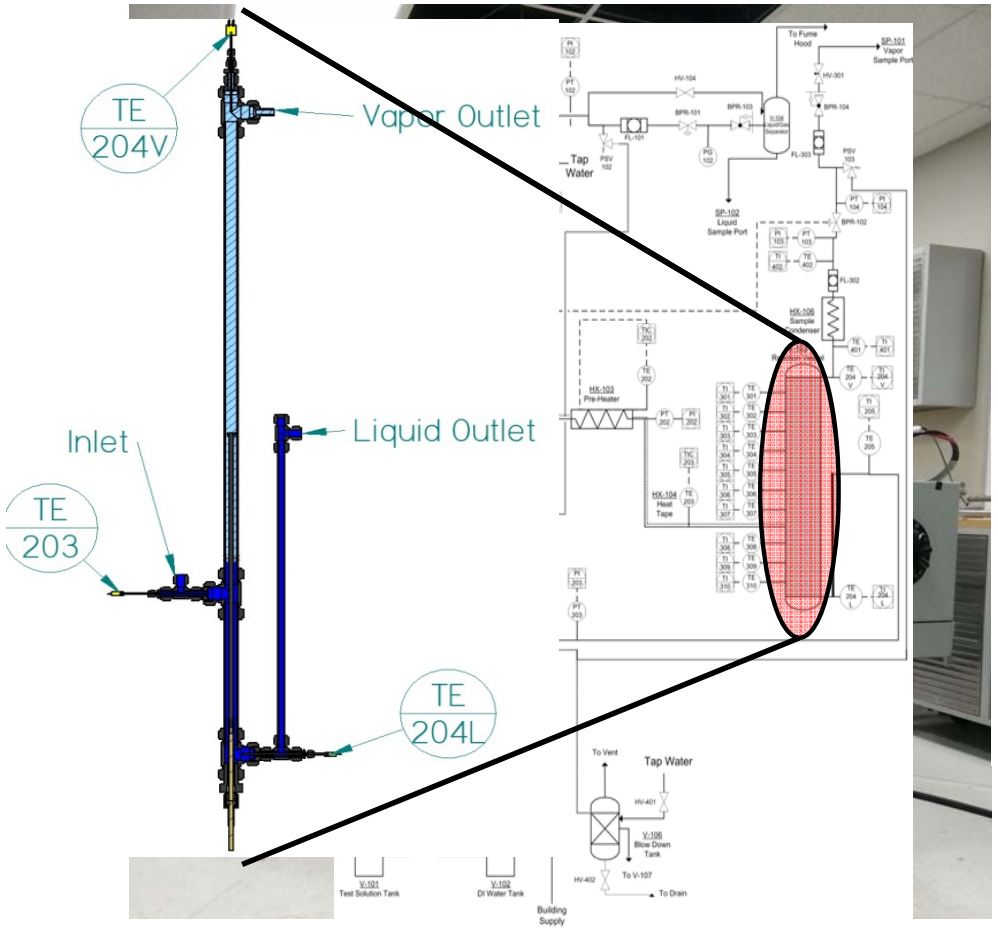
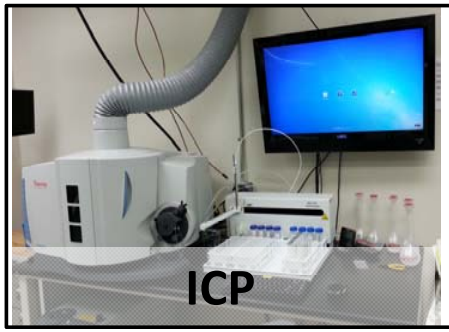
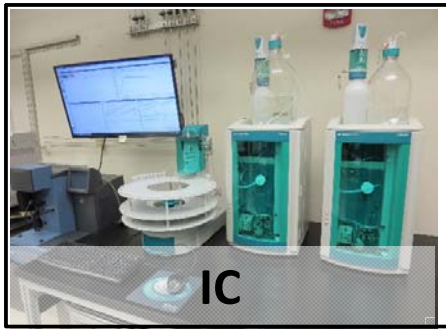


Figure 6. OHIO Prototype Brine Treatment System

Analytical Procedures



- **Model:** Thermo iCAP 6000 ICP
- **Purpose:** Determine Na^{+}, Mg^{2+}, Ca^{2+}, and aqueous silicate content



- **Model:** Metrohm 930 Compact IC
- **Purpose:** Determine HCO_3^- Cl^- and SO_4^{2-} content

Table 1. Experimental Test Solutions

Test Solution	50 (g/L)	180 (g/L)
Ions	Concentration (mg/L)	
Na^+	14,956	53,429
Ca_2^+	4,261	15,222
Ba_2^+	27	97
Sr_2^+	109	389
K^+	54	194
Cl^-	30,671	109,572
HCO_3^-	82	292
SO_4^{2-}	109	389
NH_3^-	109	389
SiO_2	10	34
TDS (mg/L)	50,387	180,008
Density (kg/m^3)	1,032	1,115

H_2O-NaCl Solution Properties

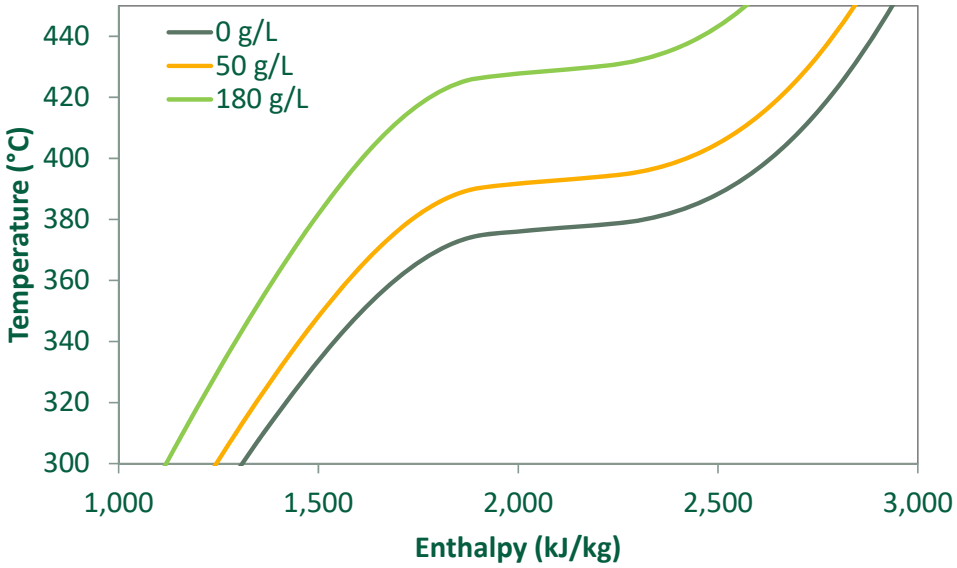


Figure 7. T-*h* diagram with lines of constant NaCl concentration at 230 bar.

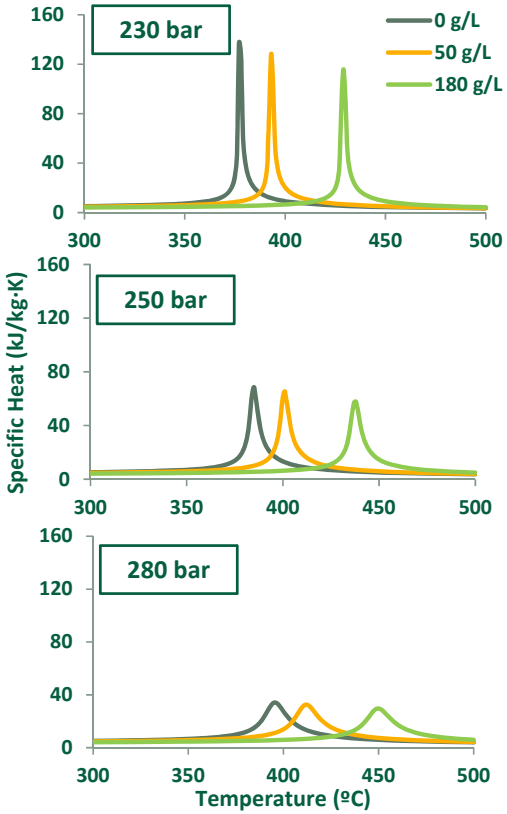


Figure 8. Specific heat capacity for water and NaCl solutions.[1]

[1] T. Driesner, Geochimica et Cosmochimica Acta, vol. 71, pp. 4902–4919, Jan. 2007.

Results Summary

Table 2. Experimental results summary for 50 and 180 g/L solutions

		Units	50 g/L		
	Pressure	bar	230.01 ± 0.45	249.99 ± 0.97	280.00 ± 1.00
Temperature	Pseudocritical	ºC	377.5	384.9	395.4
	Experimental Psuedocritical		379.1 ± 0.47	386.3 ± 0.53	397.3 ± 2.65
	Vapor Outlet		387.2 ± 0.64	391.0 ± 0.32	406.4 ± 0.06
	Liquid Outlet		369.5 ± 4.63	373.7 ± 10.91	388.2 ± 7.03
Total Dissolved Solids	Water Product	mg/L	655.1 ± 158.5	1,240.0 ± 237.7	2,836.1 ± 97.5

		Units	180 g/L		
	Pressure	Bar	230.00 ± 0.31	249.99 ± 0.89	280.00 ± 0.17
Temperature	Pseudocritical	ºC	377.5	384.9	395.4
	Experimental Psuedocritical		380.1 ± 1.43	387.8 ± 1.19	398.4 ± 1.55
	Vapor Outlet		378.7 ± 0.87	390.3 ± 0.74	402.7 ± 0.63
	Liquid Outlet		381.9 ± 1.16	392.0 ± 0.74	404.2 ± 0.76
Total Dissolved Solids	Water Product	mg/L	589.4 ± 40.9	1,095.4 ± 75.2	2,616.1 ±247.2

Water Product Purity

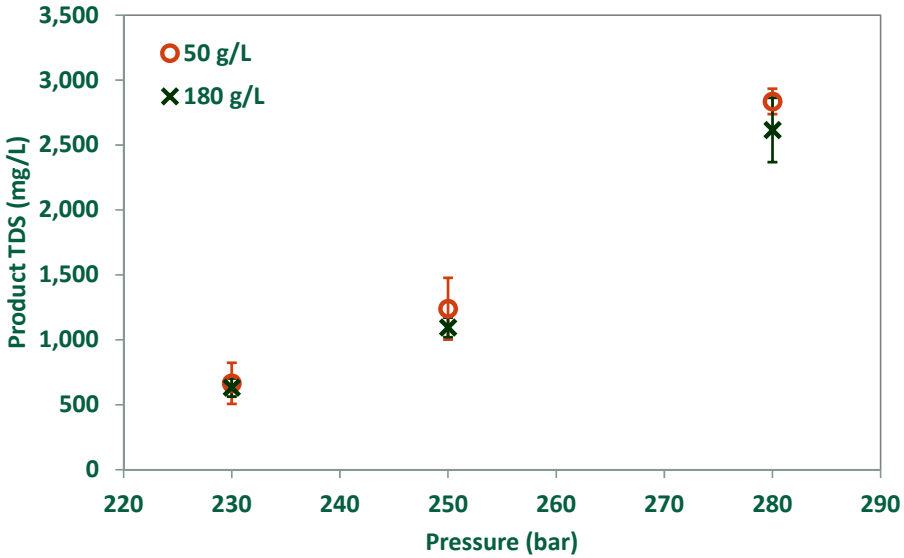


Figure 9. Water product purity with pressure.

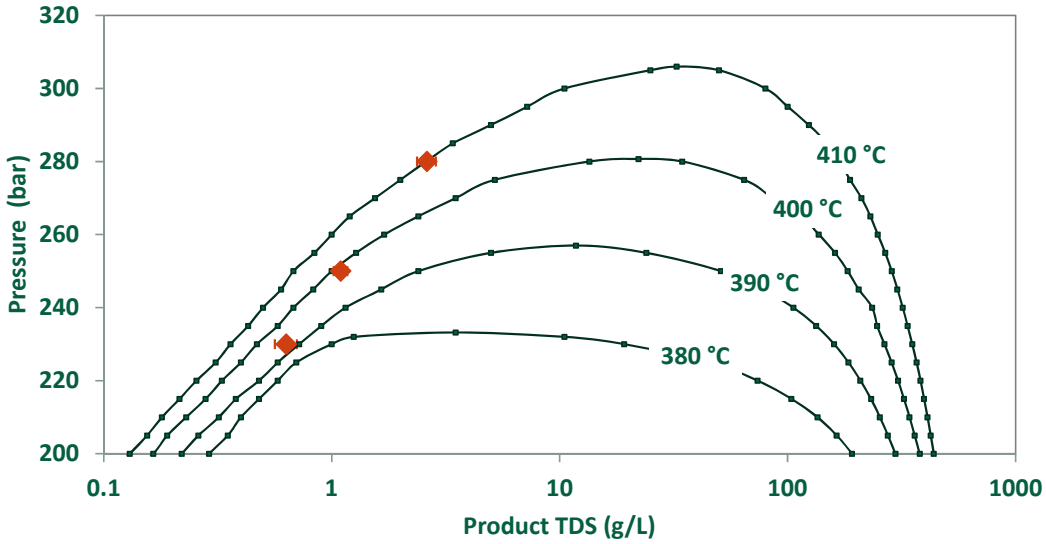


Figure 10. Pressure with vapor TDS concentration and lines of constant temperature [2].

[2]J. L. Bischoff and K. S. Pitzer, American Journal of Science, p. 217, 1989.

Water Recovery

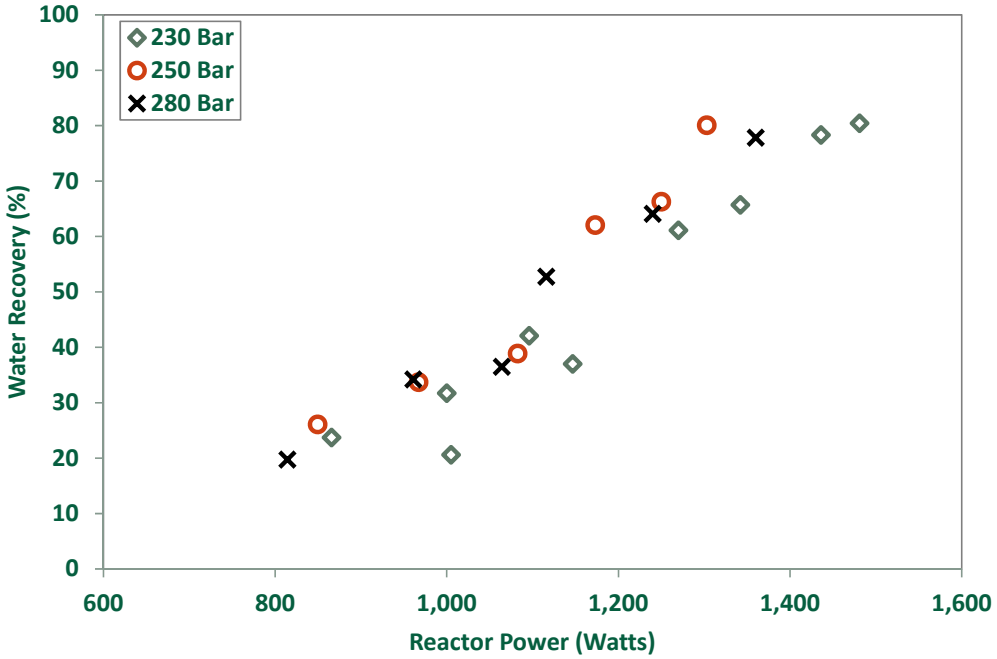


Figure 12. Water recovery rates plotted with desalinator power. $\dot{m} = 100$ g/minute.

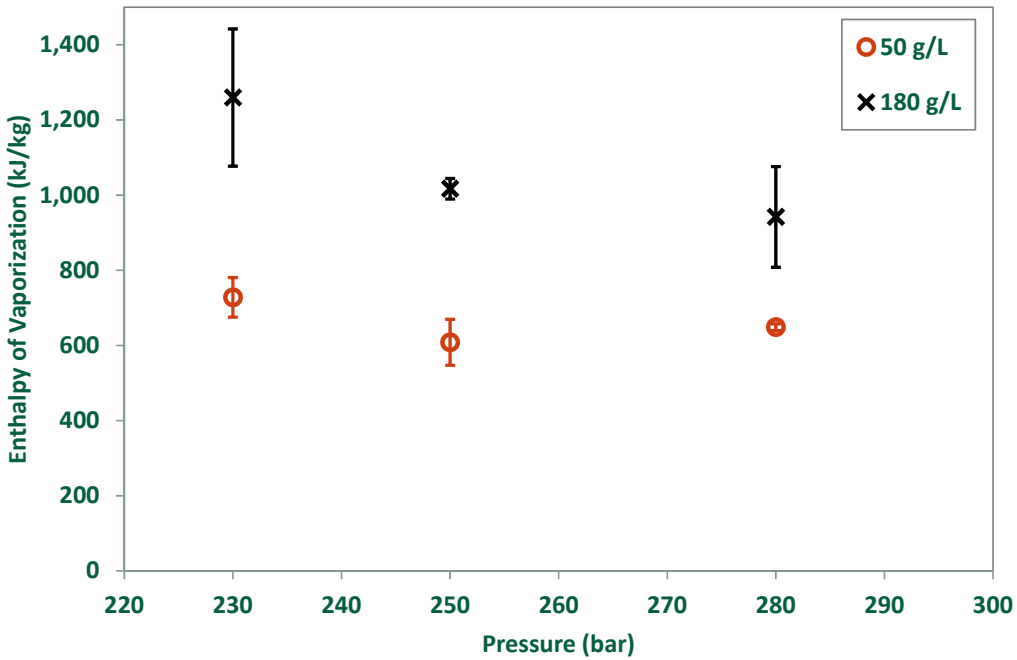


Figure 13. Experimentally derived enthalpy of vaporization estimates.

Process Modeling & Techno-economics

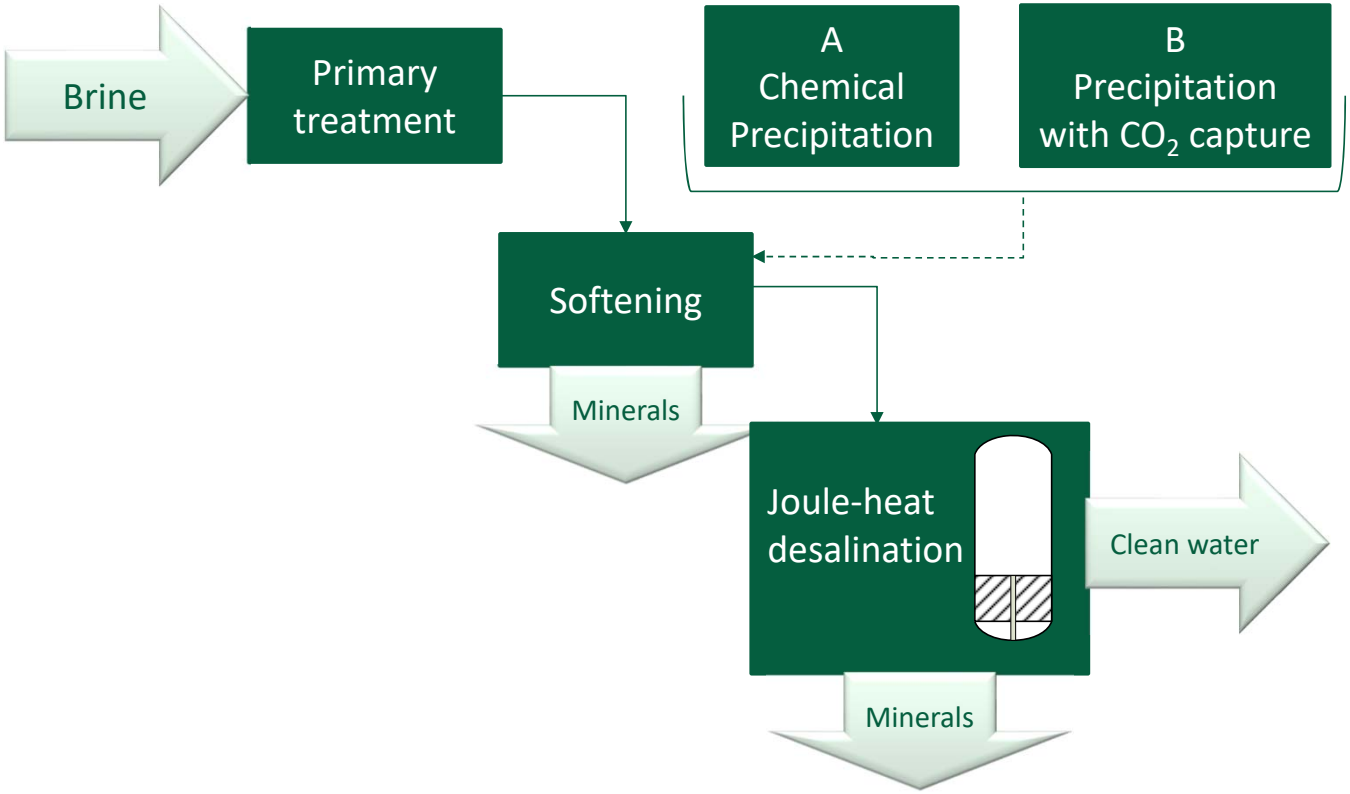
Model Overview

Aspen Plus® desalination simulation	
Software	Aspen Plus® V9
Thermodynamic property method	ELECNRTL
Water chemistry	Produced water
Nameplate plant capacity	500 GPM of brine (> 15 wt. %)
Feed conditions	25 °C and 1 bar
Economic Assessment	
Capital Expense	• APEA (Aspen Process Economic Analyzer) • AED&R (Aspen Exchanger Design & Rating) • Cost charts • Vendor quotes
Year basis	2015
Capacity factor	0.85
Interest rate (capital charge factor)	10 %
Cost Units	U.S. dollars

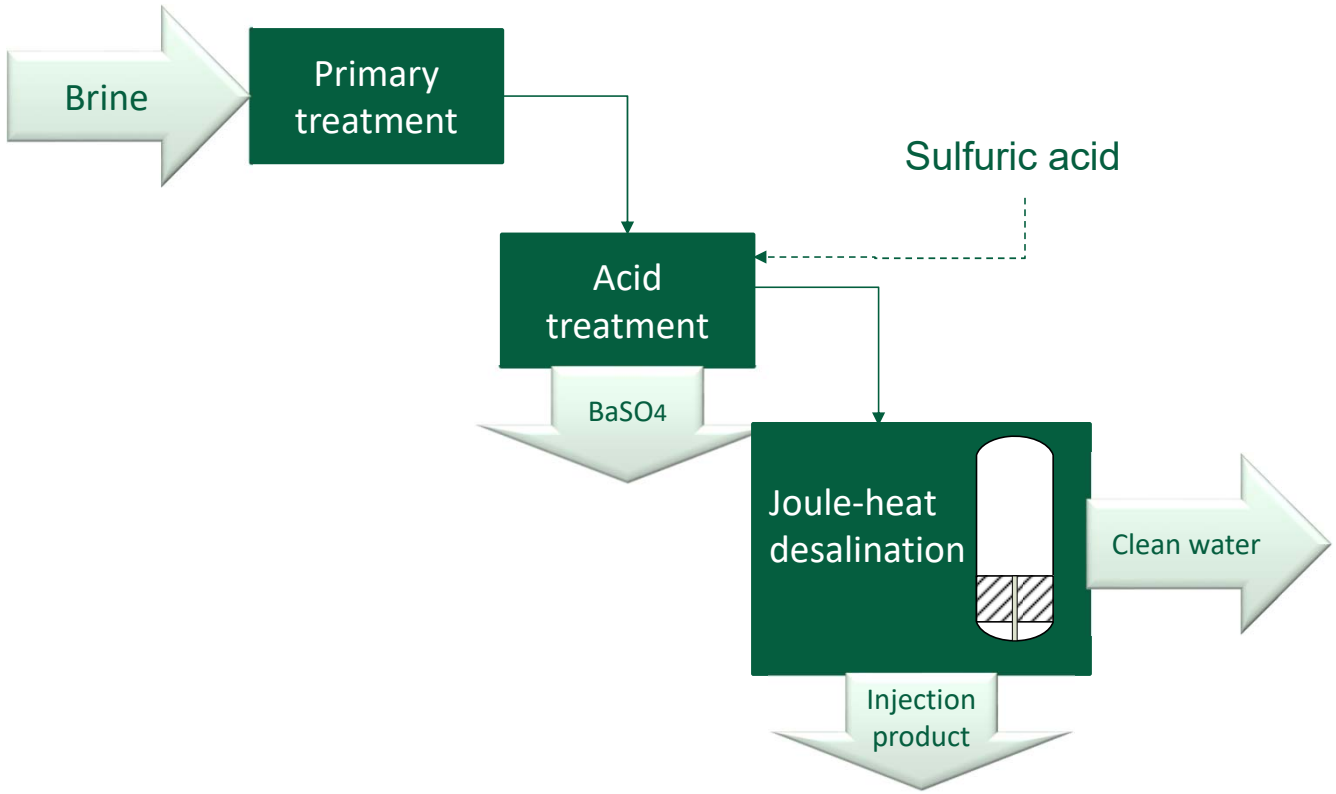
Table 3. Model Brine Composition

Constituent	Concentration (mg/L)	Molarity (mol/L)
Na^{+}	37,939.0	1.650
Ca^{2+}	12,575.0	0.314
Ba^{2+}	7,944.6	0.058
Sr^{2+}	4,153.8	0.047
Mg^{2+}	1,106.4	0.046
Cl^{-}	90,869.3	2.563
SO_4^{2-}	779.0	0.008
TDS	155,336.1	

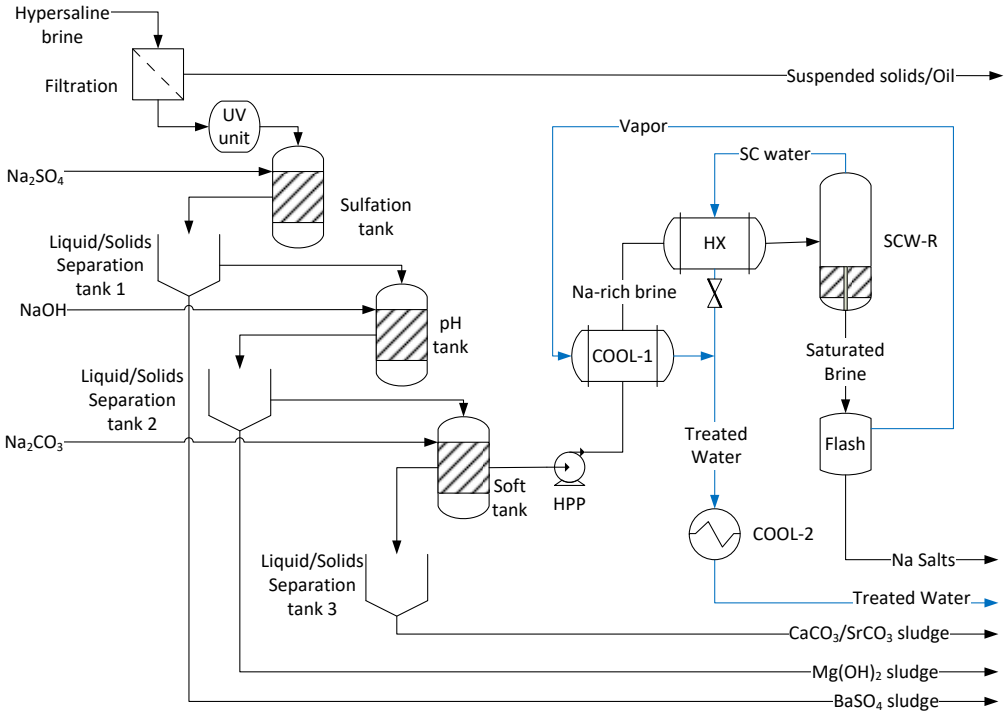
Model Scenarios (A & B)



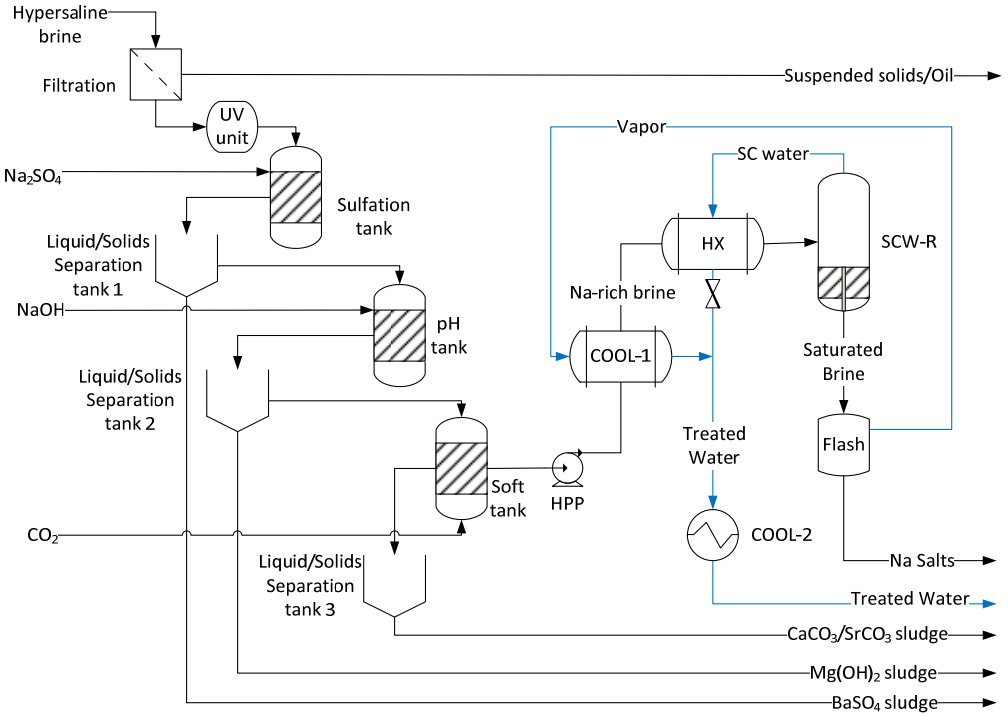
Model Scenarios (C)



Process Flow Diagrams

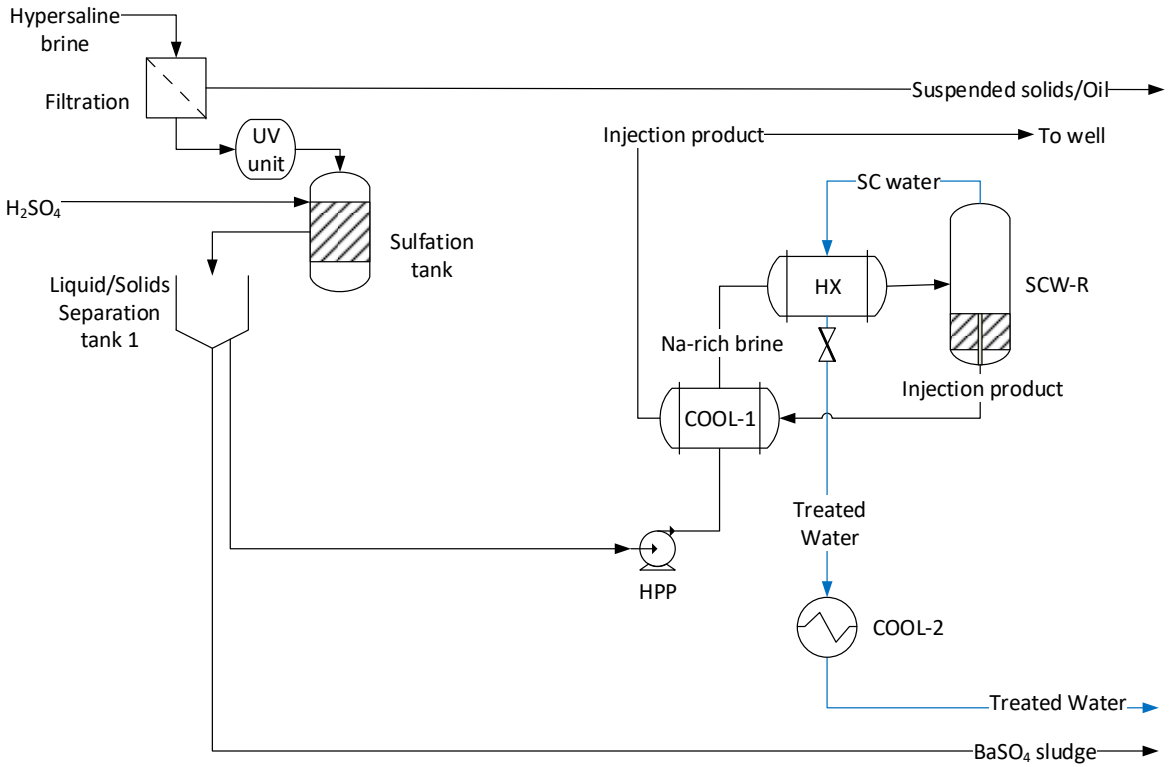


Scenario A



Scenario B

Process Flow Diagrams



Scenario C

Joule Model Confirmation

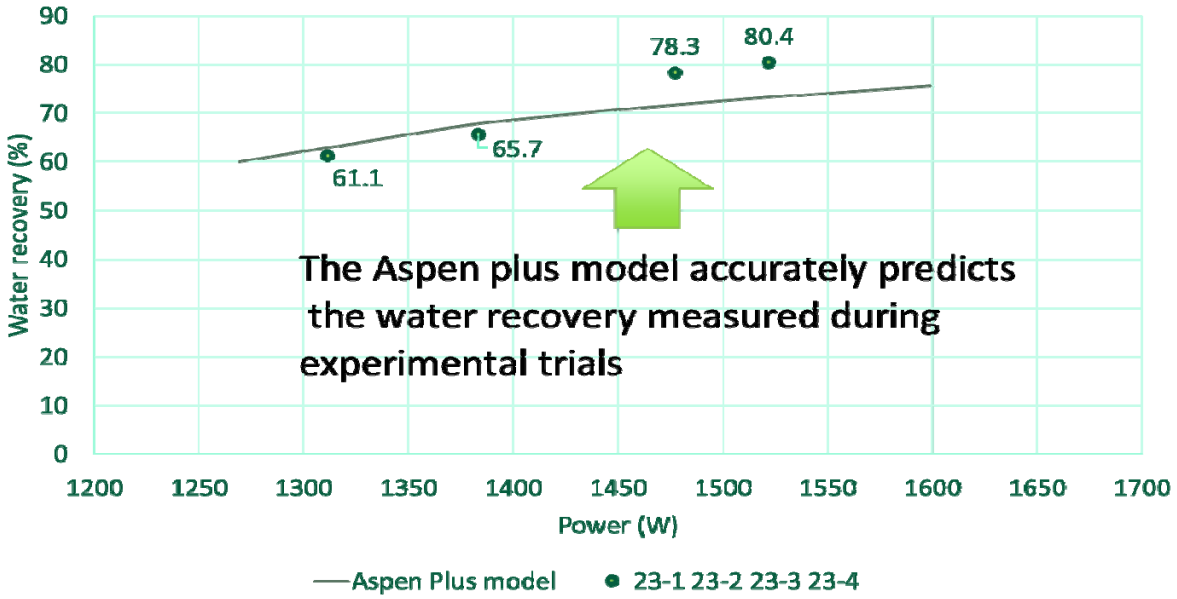
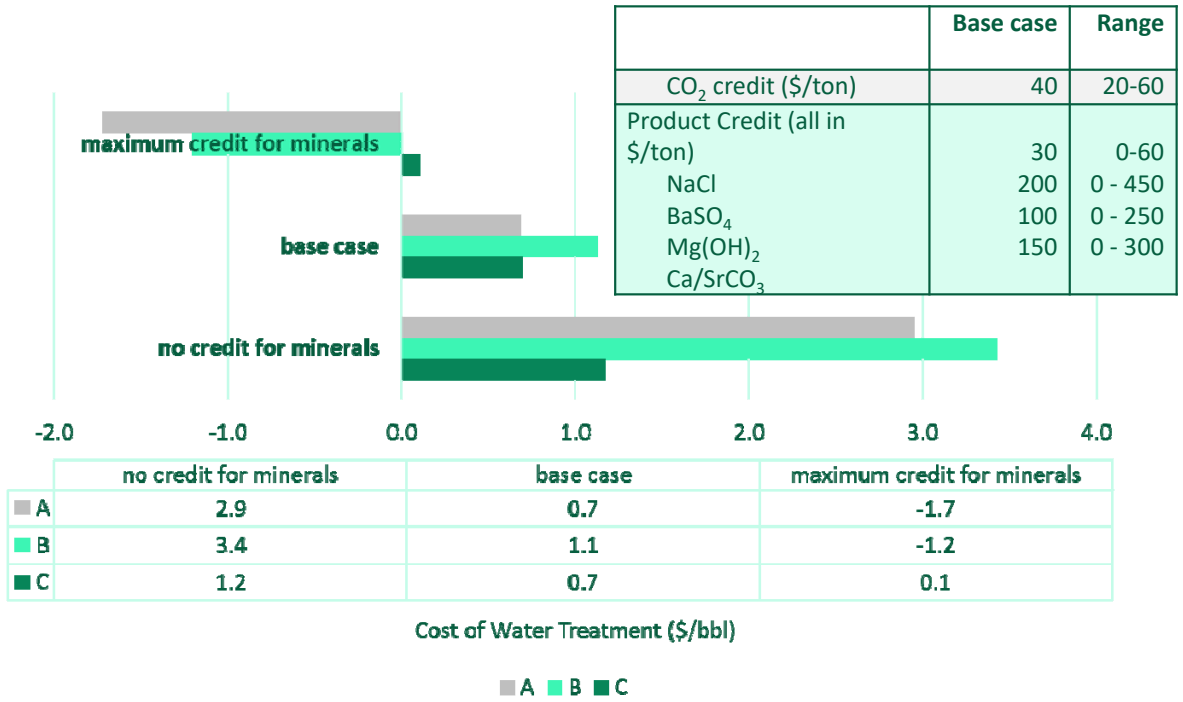


Figure 14. Experimental and model water recovery with Joule heater power.

Scenario Comparisons



	Base case	Range
CO_2 credit ($/ton)	40	20-60
Product Credit (all in $/ton)	30	0-60
NaCl	200	0 - 450
$BaSO_4$	100	0 - 250
$Mg(OH)_2$	150	0 - 300
$Ca/SrCO_3$		

	no credit for minerals	base case	maximum credit for minerals
A	2.9	0.7	-1.7
B	3.4	1.1	-1.2
C	1.2	0.7	0.1

Table 4. Scenario Cost Comparison

	Scenario A	Scenario B	Scenario C
Brine flow (GPM)	500	500	500
Capital cost ($M)*	7.8	8.6	7.5
Mineral product (tons/day)	597	594	40
Treatment cost ($/bbl)	0.7	1.2	0.7

* uncertainty +40%/-25 %

Summary

Summary

- Selective ion removal
  - Electrocoagulation tests completed with Marcellus shale brine
  - Removal selectivity likely based upon respective cation hydroxide solubility
- Joule brine treatment
  - Wide range of brine solutions containing 50 to 180 g/L tested
  - Ability to produce clean water product containing 600-2,800 mg/L TDS
  - Over 1,000 hours of operational experience gained
- Process modeling & techno-economics
  - Thermodynamic model accuracy for non-ideal brine solutions confirmed with experimental results
  - Three process scenarios modeled ranging from zero liquid discharge to concentration with injection
  - Promising estimated brine treatment costs ranging from 0.7-1.2 $/bbl

Acknowledgements

- WVU colleagues Ms. Xiujuan Chen and Dr. Xingbo Liu
- Mr. David Ogden and Dr. Dora Lopez for their efforts in developing the experimental apparatus/testing, process simulation, and costing
- Project manager Barbara Carney for her insight and National Energy Technology Laboratory (DE-FE-0026315) for their financial support

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Questions: Jason Trembly
Website: https://www.ohio.edu/engineering/isee/
E-mail: trembly@ohio.edu
Phone: (740) 566-7046

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Supporting Slides

Kinetic Modeling of Electro-Coagulation

❖ The mass conservation of metal ions during EC process can be generally expressed as:

$(-r_D)$ is the removal rate of metal ions.

- First-order model, $(-r_D) = -K_1 C_t$,

  $\ln C_t = -K_1 t + \ln C_0$

  simplified as:

  $C_t = C_0 \exp(-K_1 t)$

- Second order model, $(-r_D) = (K_2(C_e - C_t)^2$, expressed as:

  $t/C_t = 1/(K_2 C_e^2) + t/C_e$

- Pseudo-first order model, $(-r_D) = K_{pse}(C_t - C_e)$, $(-r_D)$ is proportional to the concentration distance at t and at equilibrium.

  $C_t = C_e + (C_0 - C_e)\, e^{-Kpseut}$

if the equilibrium concentration is extremely low, even zero value, the pseudo-first order model gets back to the first-order model.

Effect of Current Densities on Removal Kinetics

CD mA/cm^2	First order model		Pseudo-first order model		
	K_1 (min^{-1})	R^2	C_e	K_1 (min^{-1})	R^2
2.1	0.0833	0.97912	0.0449	0.10926	0.98756
4.2	0.14775	0.99463	-0.554	0.14312	0.99387
8.3	0.21087	0.99868	-0.5129	0.20458	0.99887
12.5	0.30142	0.99956	-0.15781	0.29825	0.99991

Table 1. The kinetic parameters for first-order and pseudo-first order model at different current densities.

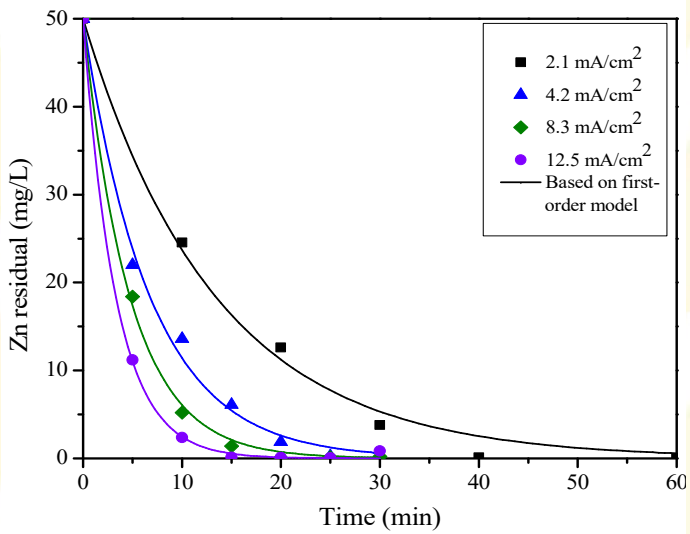


Fig. 5 Effect of current density on removal of Zn.

- Removal of zinc ions by EC process follows the first-order model with current- dependent parameters.

Effect of Initial Concentrations on Removal Kinetics

Initial Con. mA/cm²	First order model		Pseudo-first order model		
	K_1 (min^{-1})	R^2	C_e	K_1 (min^{-1})	R^2
50	0.21087	0.99868	-0.5129	0.20458	0.99887
100	0.14848	0.9983	-0.68998	0.14534	0.99827
250	0.06486	0.99426	-12.32778	0.05747	0.99755
500	0.03619	0.96677	0.99755	0.05199	0.98110
1000	0.01304	0.90758	481.70668	0.04072	0.97532
2000	0.00962	0.84684	1213.02075	0.04663	0.97029

Table 2. The kinetic parameters for first-order and pseudo-first order model at different concentrations.

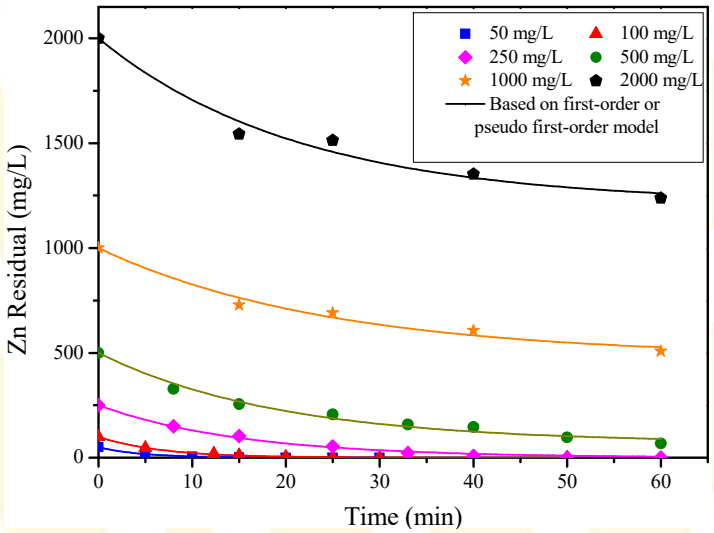
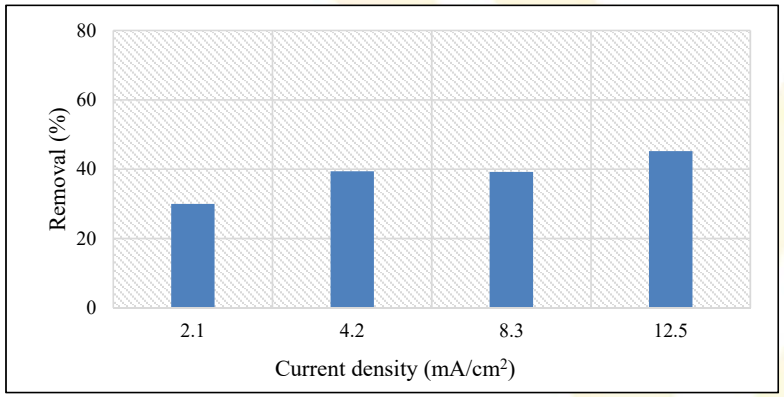


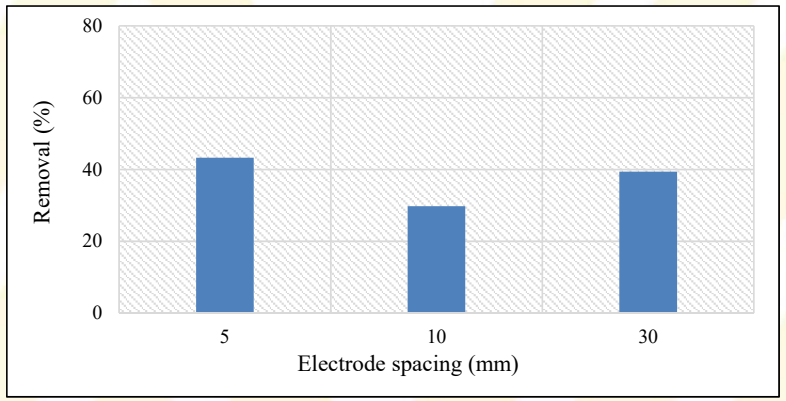
Fig. 6 Effect of zinc initial concentration on removal of Zn.

❖ Removal of zinc ions fits with the first order model at related low concentration (50, 100 and 250 mg/L), and fits will with the pseudo-first order model at high concentrations (500, 1000 and 2000 mg/L).

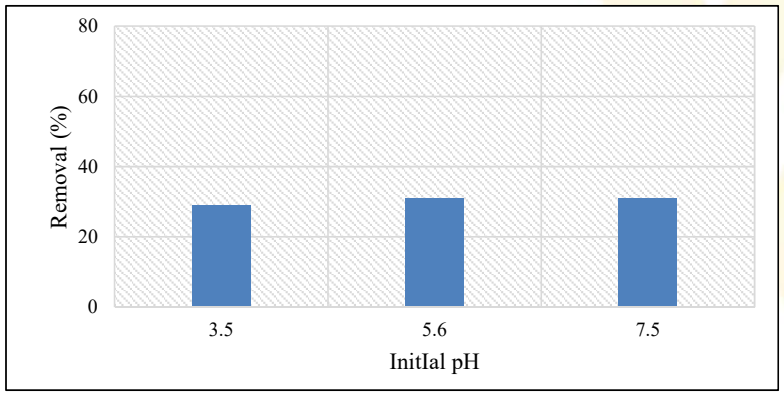
Removal of Strontium Ions



C_0 = 10 mg/L, t = 60 min, d = 10 mm, pH = 5.6



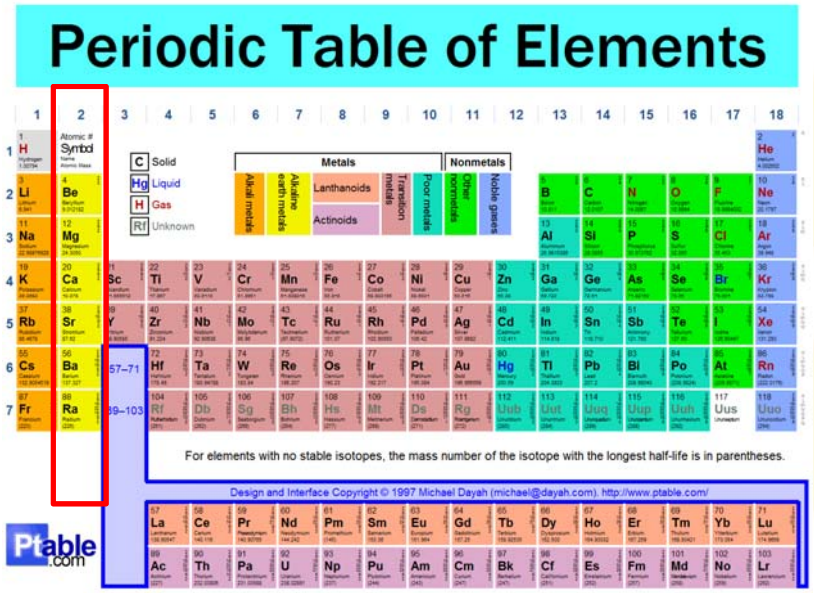
C_0 = 10 mg/L, d = 10 mm, CD = 2.1 mA/cm^2, pH = 5.6



C_0 = 10 mg/L, t = 30 min, d = 10 mm, CD = 2.1 mA/cm^2

The slower removal of Sr^{2+} compared to Fe^{3+}, Cu^{2+} and Zn^{2+} is attributed to a difference in the removal mechanisms

Possible Removal Mechanisms: Electrostatic Attraction



Mg, Ca, Sr and Ba locate in the same group

Atomic radius: Ba > Sr > Ca > Mg

Electronegativity: Mg > Ca > Sr > Ba

Ability of electrostatic attraction: Mg > Ca > Sr > Ba

Removal efficiency: Mg > Ca > Sr > Ba

Other possible removal mechanisms reported in literature include surface complexation.

Water Product Purity

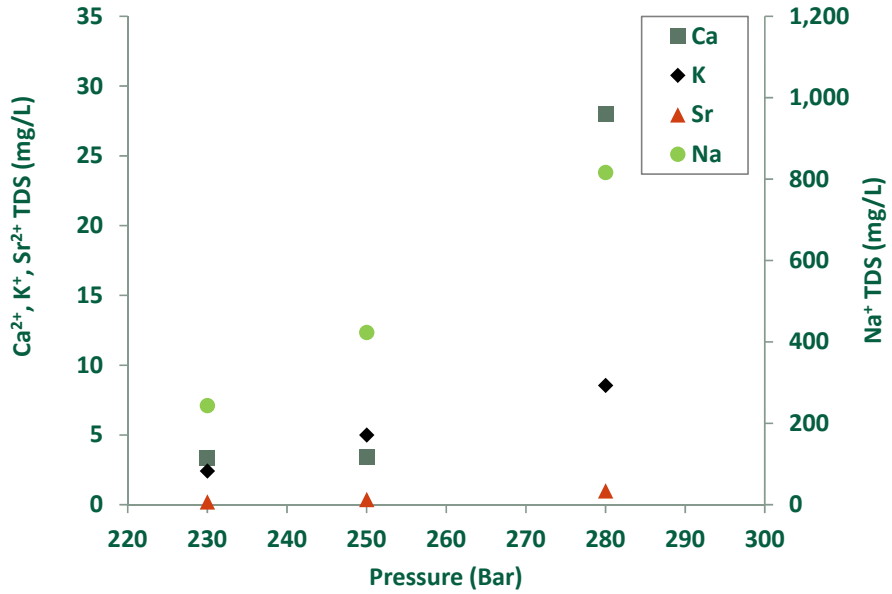
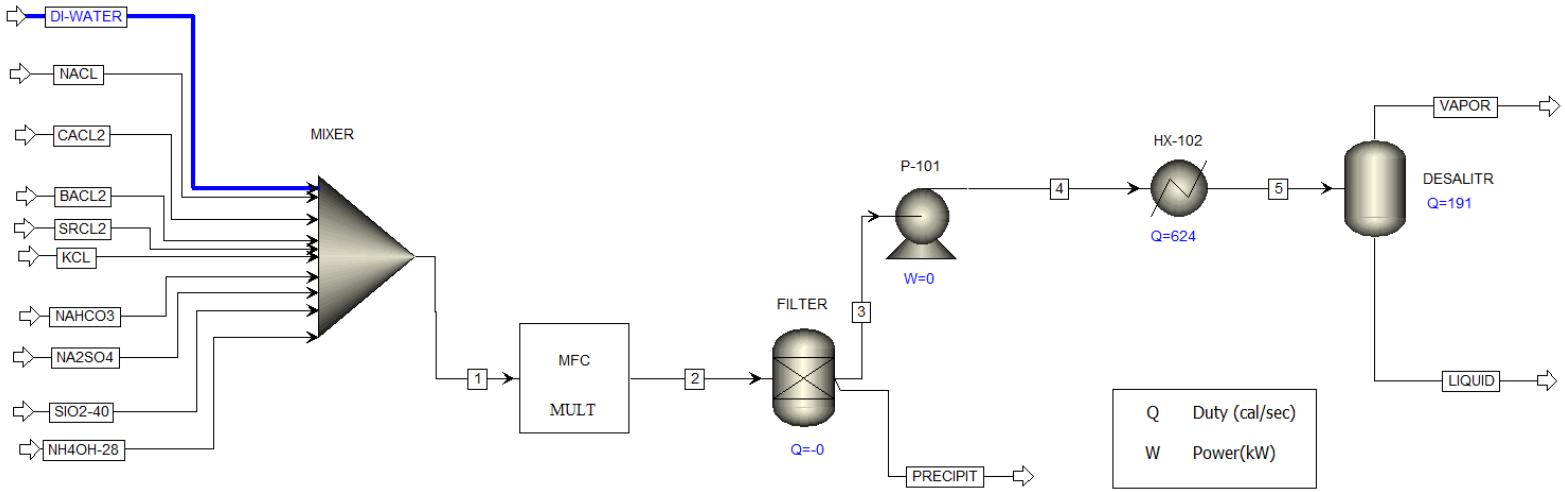


Figure 11. Major cation concentrations found in water product with pressure.

Aspen Plus model overview to estimate properties and validate the experimental results

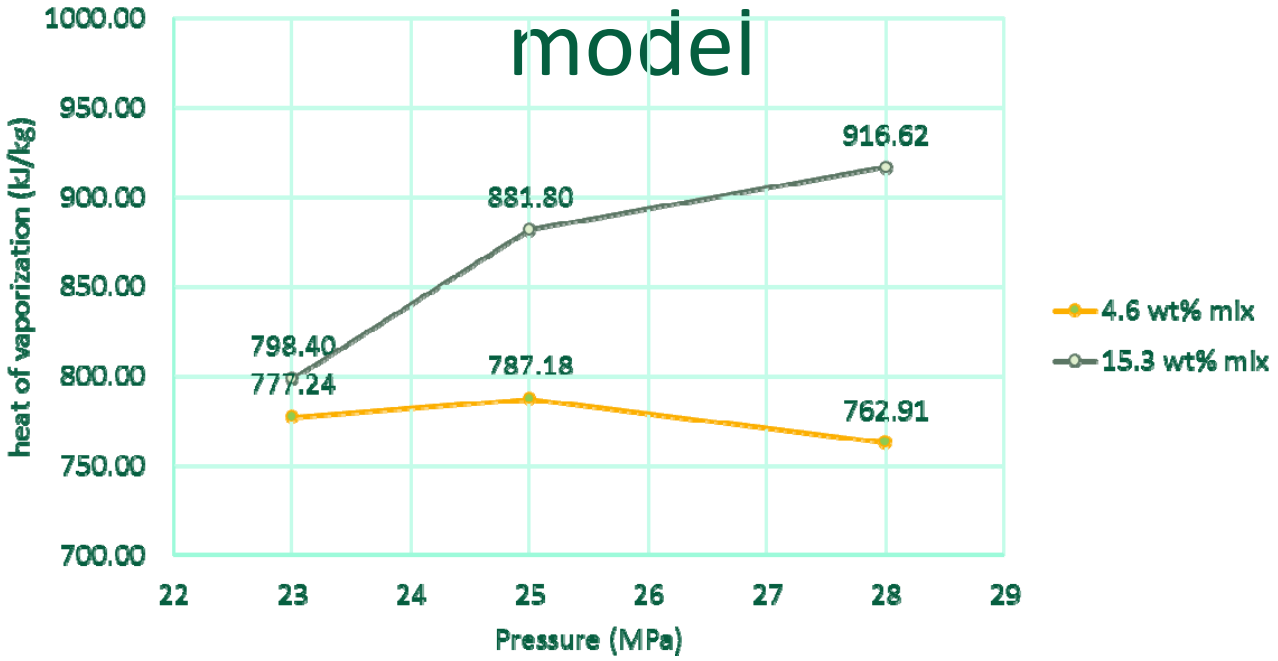
We are currently in the process of estimating properties and desalination results

- Enthalpy of vaporization
- Chemistry (precipitation)
- pH
- Energy balances
- Water recovery %
- Heat Capacity
- TVLE
- Power requirements

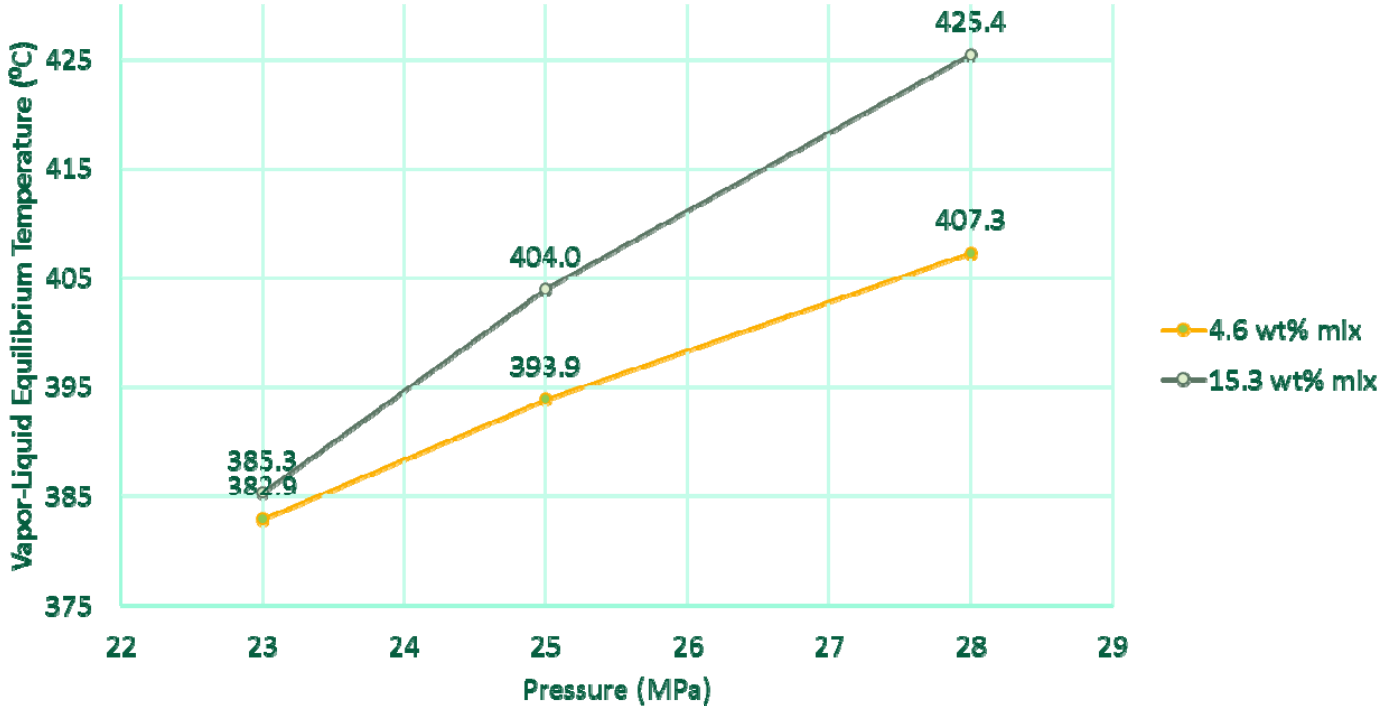


See appendix B for Chemistry

Minimum Enthalpy of Vaporization estimated from the Aspen Plus model

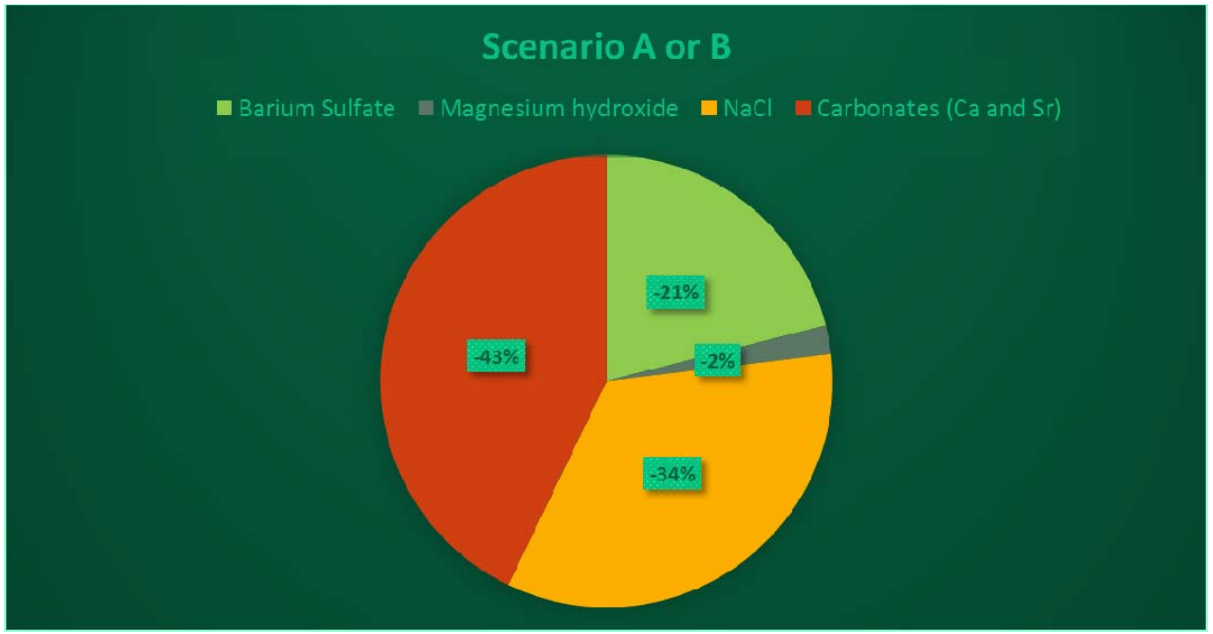


TVLE from the Aspen Plus model



Other supporting slides

Solid product breakdown



100% of solid credit in Scenario C comes from $BaSO_4$

Appendix A. Chemistry employed in the cost model

Reaction Type	Chemical Equation	
Equilibrium	$MgOH^{+} \leftrightarrow OH^{-} + Mg^{+2}$	A. 1)
Equilibrium	$CaOH^{+} \leftrightarrow OH^{-} + Ca^{+2}$	A. 2)
Equilibrium	$H_2O + HSO_4^{-2} \leftrightarrow H_3O^{+} + SO_4^{+2}$	A. 3)
Equilibrium	$H_2O + HCl \leftrightarrow H_3O^{+} + Cl^{-}$	A. 4)
Equilibrium	$H_2O + H_2SO_4 \leftrightarrow H_3O^{+} + HSO_4^{-}$	A. 5)
Equilibrium	$H_2O + HCO_3^{-} \leftrightarrow H_3O^{+} + CO_3^{-2}$	A. 6)
Equilibrium	$2\,H_2O \leftrightarrow H_3O^{+} + OH^{-}$	A. 7)
Equilibrium	$2\,H_2O + CO_2 \leftrightarrow HCO_3^{-} + H_3O^{+}$	A. 8)
Equilibrium	$Sr(OH)^{+} \leftrightarrow OH^{-} + Sr^{+2}$	A. 9)
Equilibrium	$Ba(OH)^{+} \leftrightarrow OH^{-} + Ba^{+2}$	A. 10)

Appendix A. Chemistry employed in the cost model

Salt	$MgCO_3 \cdot 3\,H_2O \leftrightarrow CO_3^{-2} + Mg^{+2} + 3\,H_2O$	A. 11)
Salt	$MgCO_3 \leftrightarrow CO_3^{-2} + Mg^{+2}$	A. 12)
Salt	$CaCO_3 \leftrightarrow CO_3^{-2} + Ca^{+2}$	A. 13)
Salt	$Mg(OH)_2 \leftrightarrow OH^- + MgOH^+$	A. 14)
Salt	$Ca(OH)_2 \leftrightarrow OH^- + CaOH^+$	A. 15)
Salt	$Na_2CO_3 \cdot 7\,H_2O \leftrightarrow 2\,Na^+ + CO_3^{-2} + 7\,H_2O$	A. 16)
Salt	$Na_2CO_3 \leftrightarrow 2\,Na^+ + CO_3^{-2}$	A. 17)
Salt	$NaOH \leftrightarrow OH^- + Na^+$	A. 18)
Salt	$SrCl_2 \cdot 2\,H_2O \leftrightarrow Sr^{+2} + 2\,H_2O + 2\,Cl^-$	A. 19)
Salt	$SrCl_2 \cdot 6\,H_2O \leftrightarrow Sr^{+2} + 6\,H_2O + 2\,Cl^-$	A. 20)

Appendix A. Chemistry employed in the cost model

Salt	$SrCl_2 \leftrightarrow Sr^{+2} + 2\ Cl^-$	A. 21)
Salt	$BaCl_2 \leftrightarrow Ba^{+2} + 2\ Cl$	A. 22)
Salt	$Na_2SO_4 \cdot 10\ H_2O \leftrightarrow 2\ Na^+ + SO_4^{-2} + 10\ H_2O$	A. 23)
Salt	$Na_2SO_4 \leftrightarrow 2\ Na^+ + SO_4^{-2}$	A. 24)
Salt	$NaCl \leftrightarrow Na^+ + Cl$	A. 25)
Salt	$SrSO_4 \leftrightarrow Sr^{+2} + SO_4^{-2}$	A. 26)
Salt	$BaSO_4 \leftrightarrow Ba^{+2} + SO_4^{-2}$	A. 27)
Salt	$NaOH \cdot H_2O \leftrightarrow OH^- + Na^+ + H_2O$	A. 28)
Salt	$Na_2CO_3 \cdot H_2O \leftrightarrow 2\ Na^+ + CO_3^{-2} + H_2O$	A. 29)
Salt	$BaCO_3 \leftrightarrow Ba^{+2} + CO_3^{-2}$	A. 30)

Appendix A. Chemistry employed in the cost model

Salt	$BaCO_3 \leftrightarrow Ba^{+2} + CO_3^{-2}$	A. 30)
Salt	$SrCO_3 \leftrightarrow Sr^{+2} + CO_3^{-2}$	A. 31)
Salt	$CaSO_4 \leftrightarrow Ca^{+2} + SO_4^{-2}$	A. 32)
Salt	$BaSO_4 \leftrightarrow Ba^{+2} + SO_4^{-2}$	A. 33)
Salt	$Ba(OH)_2 \leftrightarrow Ba(OH)^{+} + OH^{-}$	A. 34)
Salt	$Sr(OH)_2 \leftrightarrow Sr(OH)^{+} + OH^{-}$	A. 35)
Dissociation	$Mg(OH)_2 \rightarrow OH^{-} + MgOH^{+}$	A. 36)
Dissociation	$Na_2CO_3 \rightarrow 2\ Na^{+} + CO_3^{-2}$	A. 37)
Dissociation	$MgCO_3 \rightarrow CO_3^{-2} + Mg^{+2}$	A. 38)
Dissociation	$CaCO_3 \rightarrow CO_3^{\ 2} + Ca^{+2}$	39)
Dissociation	$NaOH \rightarrow OH^{-} + Na^{+}$	A. 40)
Dissociation	$SrSO_4 \rightarrow Sr^{+2} + SO_4^{-2}$	A. 41)
Dissociation	$BaSO_4 \rightarrow Ba^{+2} + SO_4^{\ 2}$	42)

Appendix B. Chemistry employed to rigorously model the experimental trials at ISEE

Reaction	Type	Stoichiometry
1	Equilibrium	HCL + H2O <--> CL- + H3O+
2	Equilibrium	H2O + HSO4- <--> H3O+ + SO4--
3	Equilibrium	H2SO4 + H2O <--> H3O+ + HSO4-
4	Equilibrium	H2O + HCO3- <--> CO3-- + H3O+
5	Equilibrium	2 H2O + CO2 <--> HCO3- + H3O+
6	Equilibrium	NH4+ + OH- <--> AMMON-01 + H2O
7	Equilibrium	H3O+ + OH- <--> 2 H2O
8	Equilibrium	CAOH+ <--> CA++ + OH-
9	Equilibrium	BAOH+ <--> BA++ + OH-
10	Equilibrium	SROH+ <--> SR++ + OH-
CACO3(S)	Salt	CACO3(S) <--> CO3-- + CA++
BACL2(S)	Salt	BACL2(S) <--> BA++ + 2 CL-
K2SO4(S)	Salt	K2SO4(S) <--> SO4-- + 2 K+
KHSO4(S)	Salt	KHSO4(S) <--> K+ + HSO4-
KCL(S)	Salt	KCL(S) <--> CL- + K+
CACL2(S)	Salt	CACL2(S) <--> CA++ + 2 CL- + 6 H2O
SALT12	Salt	SALT12 <--> CA++ + 2 CL-
SRSO4(S)	Salt	SRSO4(S) <--> SO4-- + SR++
SRCL2(S)	Salt	SRCL2(S) <--> SR++ + 2 CL-
BASO4(S)	Salt	BASO4(S) <--> BA++ + SO4--
WEGSC(S)	Salt	WEGSC(S) <--> CO3-- + 3 HCO3- + 5 NA+
TRONA(S)	Salt	TRONA(S) <--> CO3-- + HCO3- + 2 H2O + 3 NA+
BACO3(S)	Salt	BACO3(S) <--> BA++ + CO3--
SALT4	Salt	SALT4 <--> CO3-- + 2 NA+ + 10 H2O
SALT3	Salt	SALT3 <--> CO3-- + 2 NA+ + 7 H2O
SALT2	Salt	SALT2 <--> H2O + CO3-- + 2 NA+
SALT1	Salt	SALT1 <--> CO3-- + 2 NA+
CASO4(S)	Salt	CASO4(S) <--> CA++ + SO4--
SALT8	Salt	SALT8 <--> CA++ + 2 CL- + 4 H2O
SALT7	Salt	SALT7 <--> H2O + CA++ + 2 CL-
SALT6	Salt	SALT6 <--> CA++ + 2 H2O + 2 CL-
KHCO3(S)	Salt	KHCO3(S) <--> HCO3- + K+
K2CO3(S)	Salt	K2CO3(S) <--> CO3-- + 2 K+
SODIU(S)	Salt	SODIU(S) <--> SO4-- + 2 NA+
NACL(S)	Salt	NACL(S) <--> CL- + NA+
CA(OH)2	Salt	CA(OH)2 <--> OH- + CAOH+
BA(OH)2	Salt	BA(OH)2 <--> BAOH+ + OH-
SR(OH)2	Salt	SR(OH)2 <--> SROH+ + OH-
SALT9	Salt	SALT9 <--> NA+ + 0.5 H2O + 0.5 CO2 + 0.5 CO3--