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Development of a Downhole Tool for Measuring Enthalpy in Geothermal Reservoirs

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LDRD
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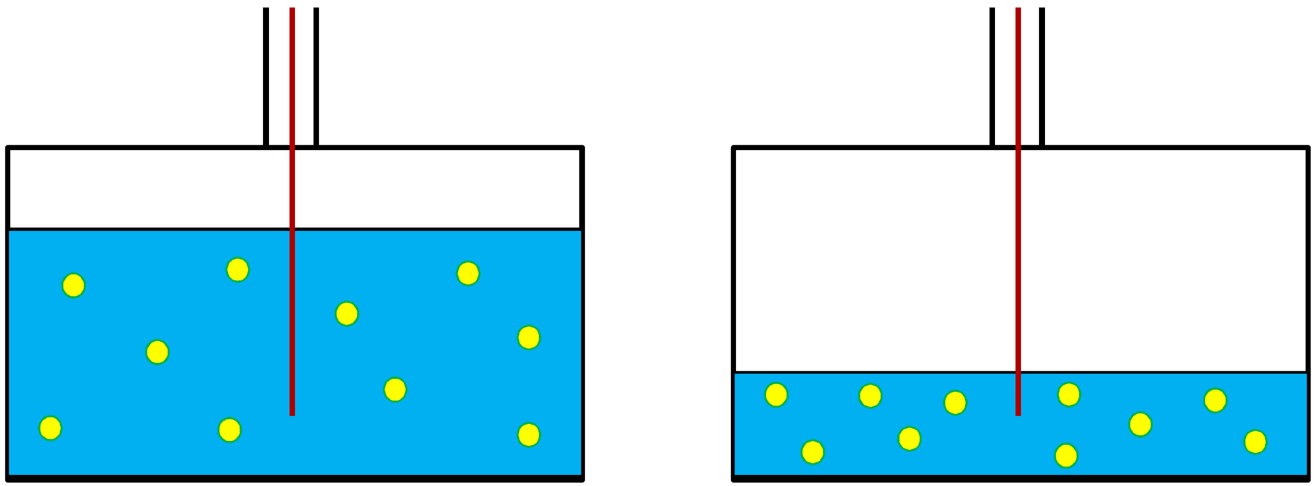
Background

- Downhole enthalpy determination parameters
  - Flow rate
  - Temperature & Pressure
  - Steam fraction
- Current Methods
  - Tracer dilution technique
    - Analyzed at off-site laboratory
    - T & P changes lead to measurement errors; not suitable for all two-phase flow
  - Acoustic method
    - Careful calibration required as well as selection of optimal frequency
  - Optical methods
    - Hydrogen darkening effects on probe and FOC from geothermal fluid

Our Approach

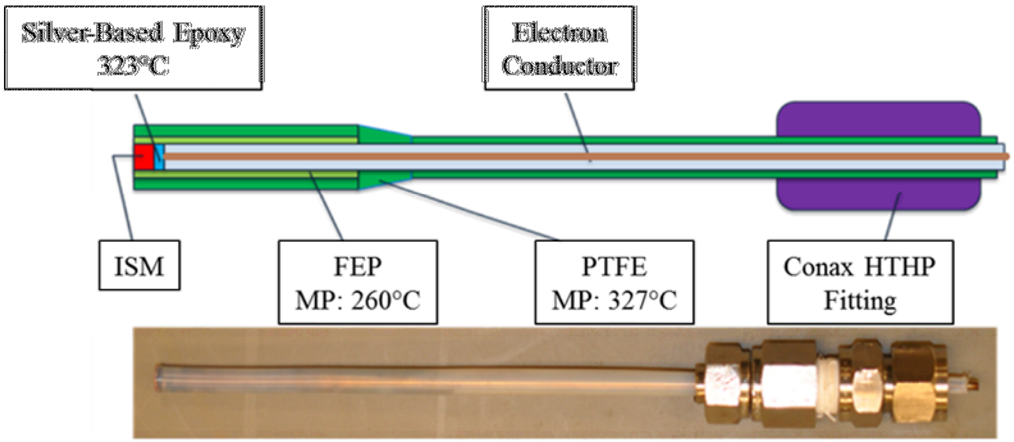
- Use of common ion in geological brine = Cl^-
- Surface measurement taken as baseline
- Change in this concentration related to steam fraction of reservoir



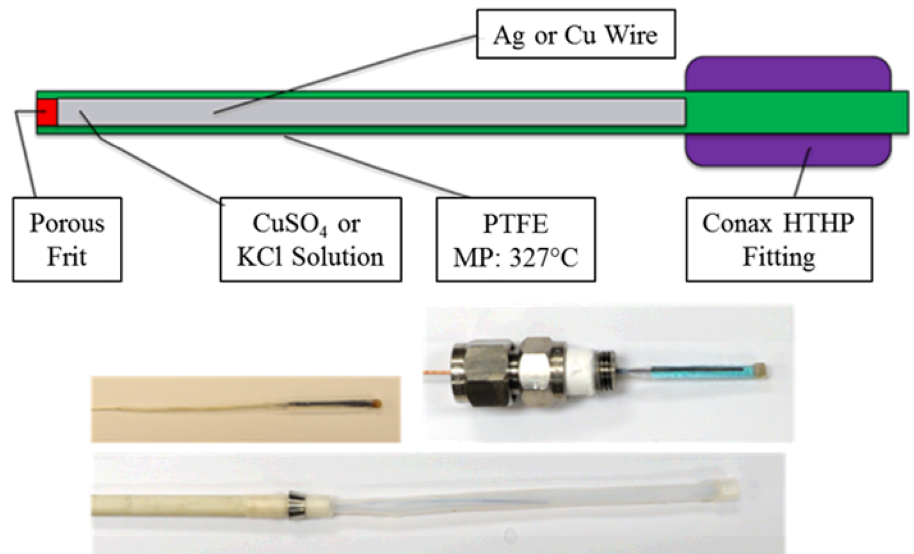
Low [Cl^-]
Low steam fraction

High [Cl^-]
High steam fraction

Electrochemical Sensor Design

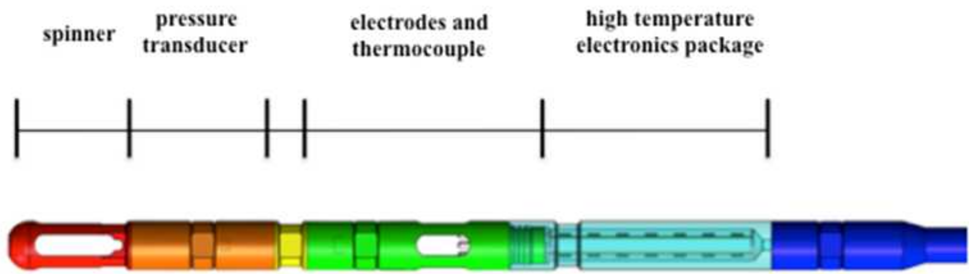


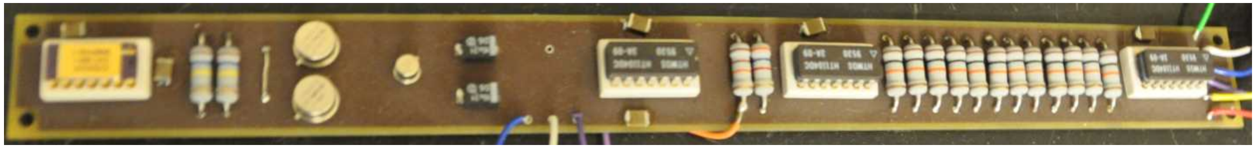
Sensor Electrode



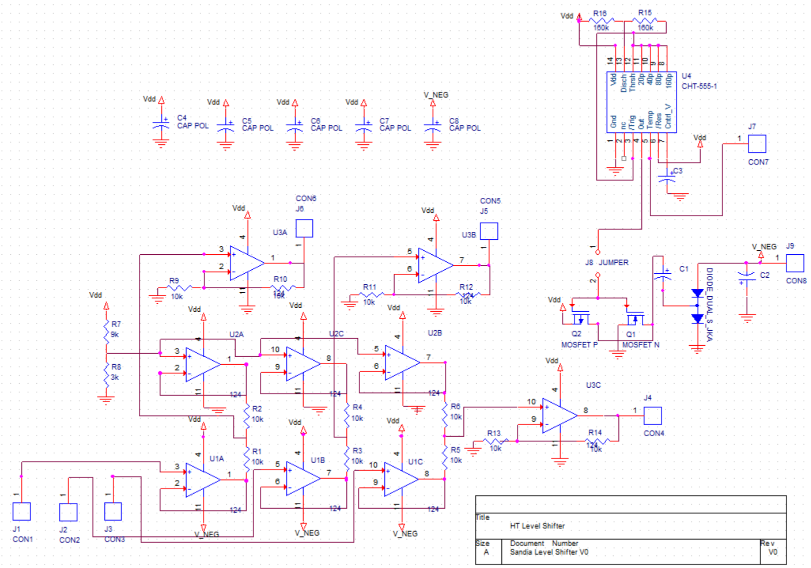
Reference Electrode

Downhole Tool Design



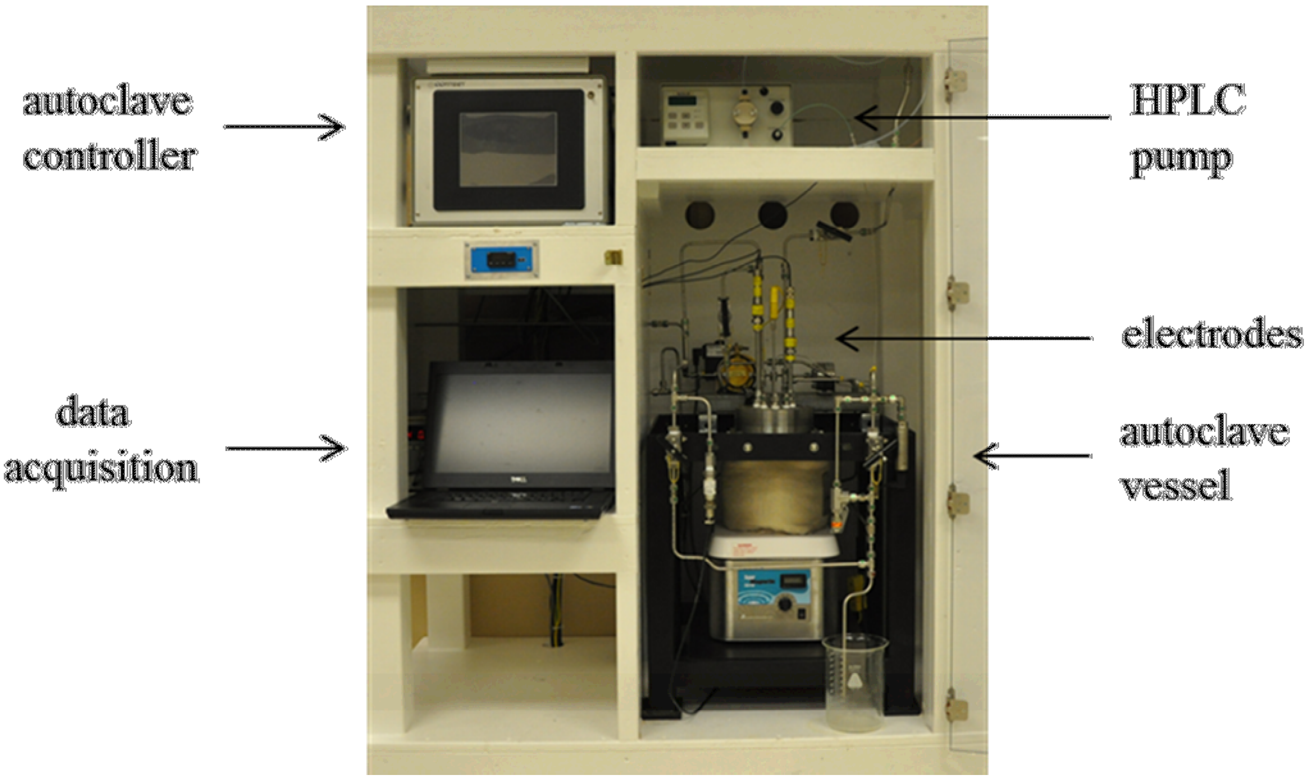


Populated printed circuit board of the electrochemical sensor signal conditioning circuitry



Circuit schematic of the high temperature signal conditioning circuitry

Autoclave System



1 L Vessel

Can run multiple electrodes at once

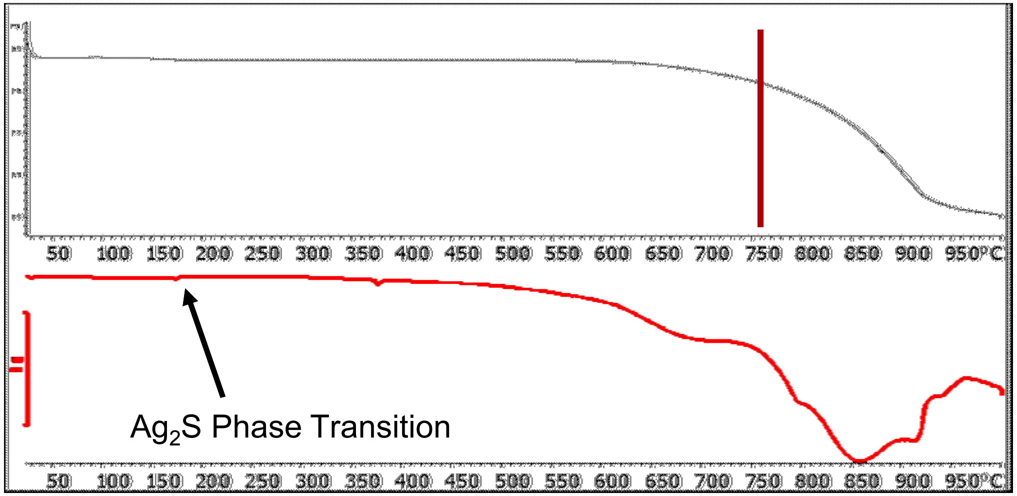
ISM Materials & Analysis

- Ag_2S = 0.3147 g
- AgCl = 0.1832 g

Ground and mixed
Pressed 15-20 min with 3T pressure

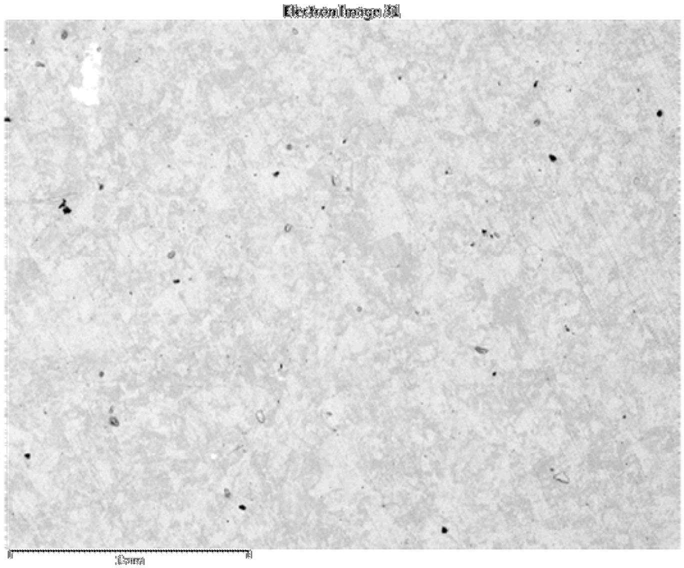
~ 0.5 g pellet of 1:1 Ag_2S/AgCl

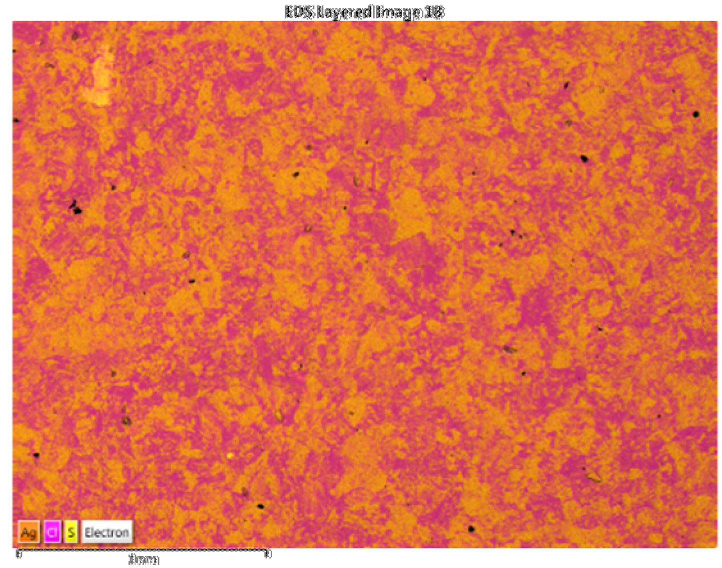
TGA



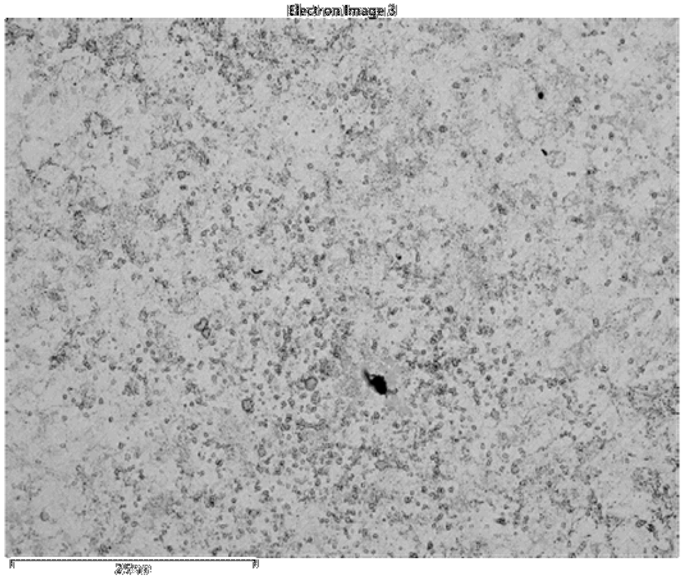
DSC

SEM/EDS





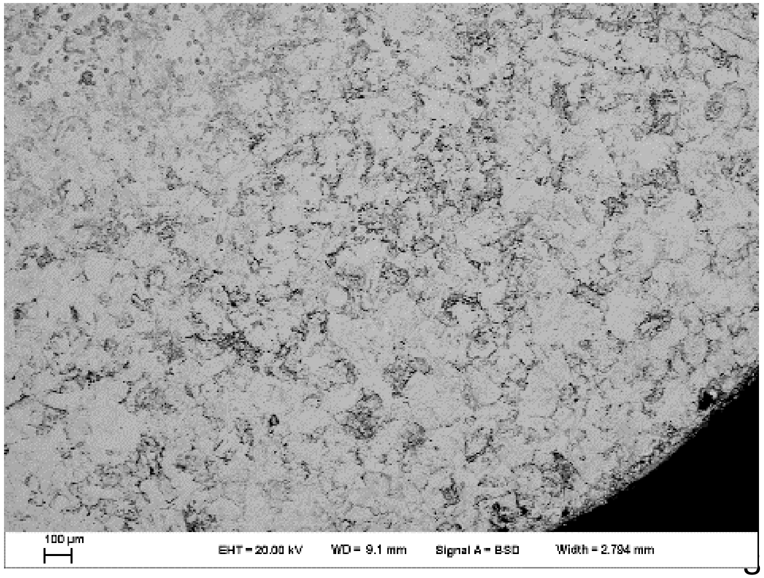
Fresh pellet



0.1 M NaCl

200°C

1 hour



SEM/EDS

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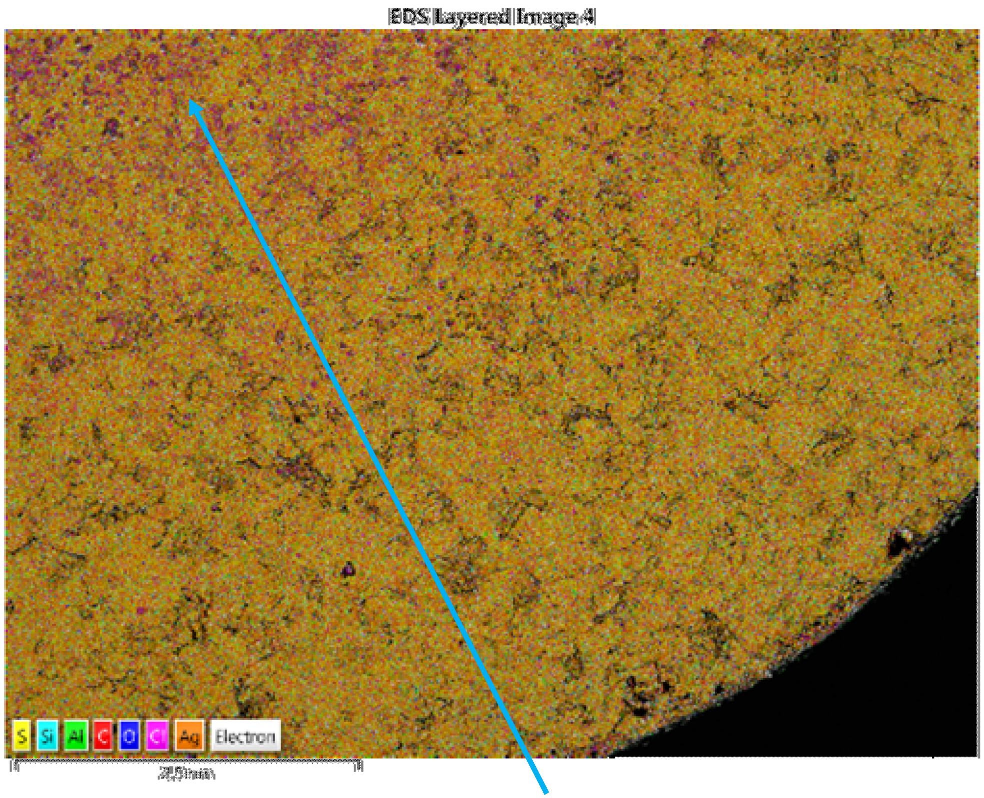


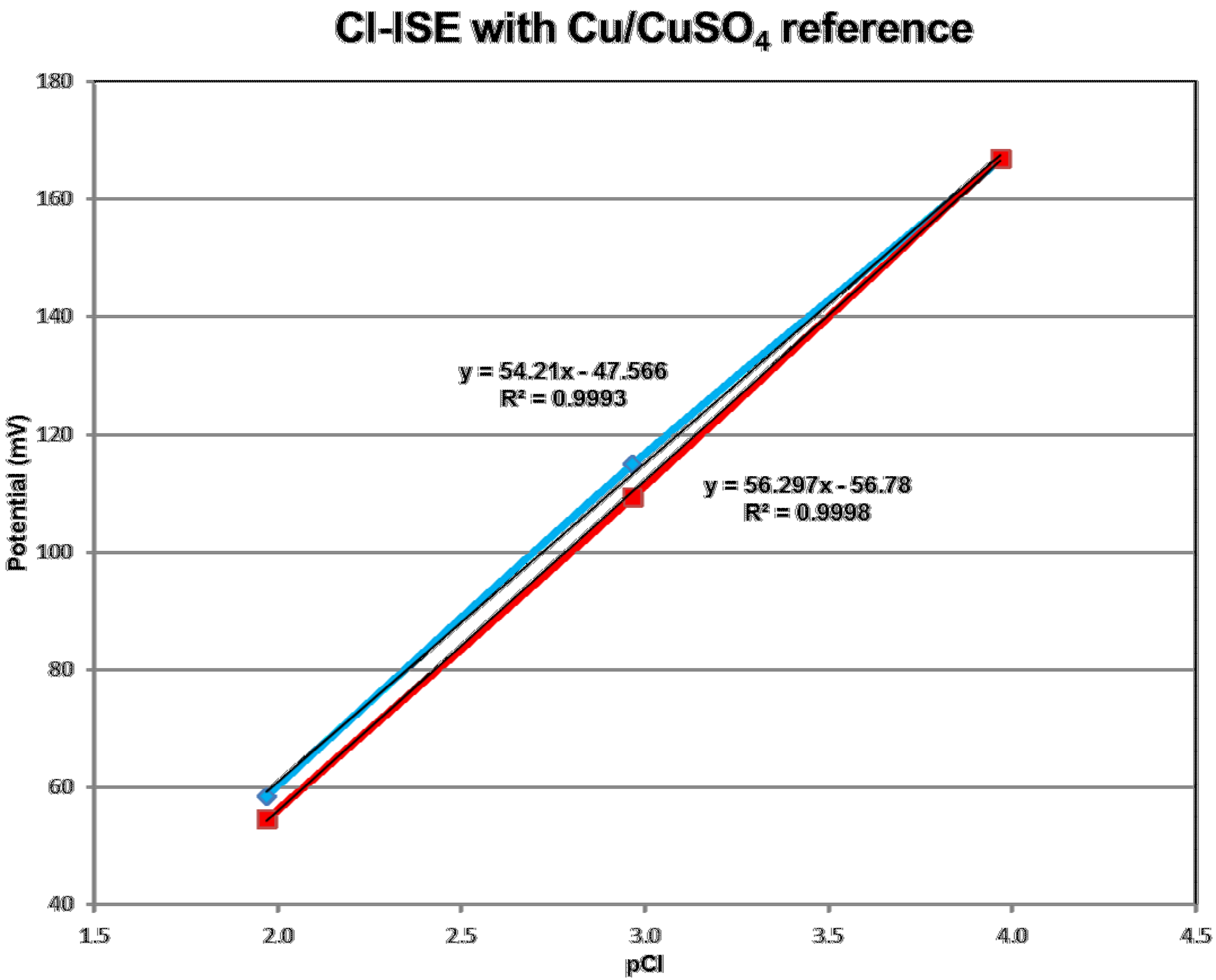
Higher concentration of Cl in interior of pellet

0.1 M NaCl

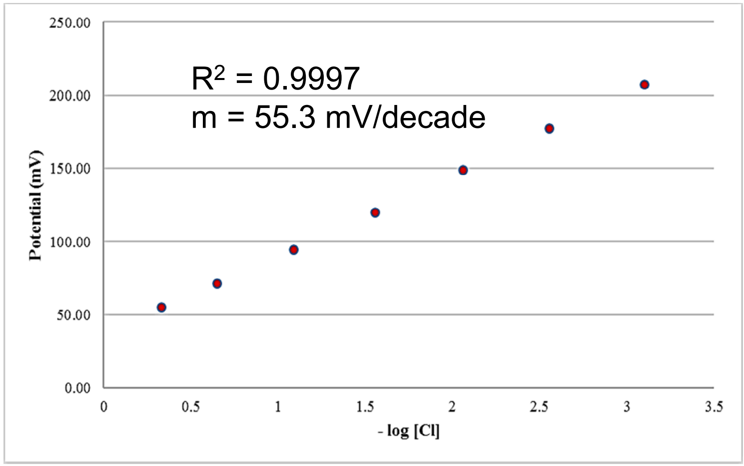
200°C

1 hour

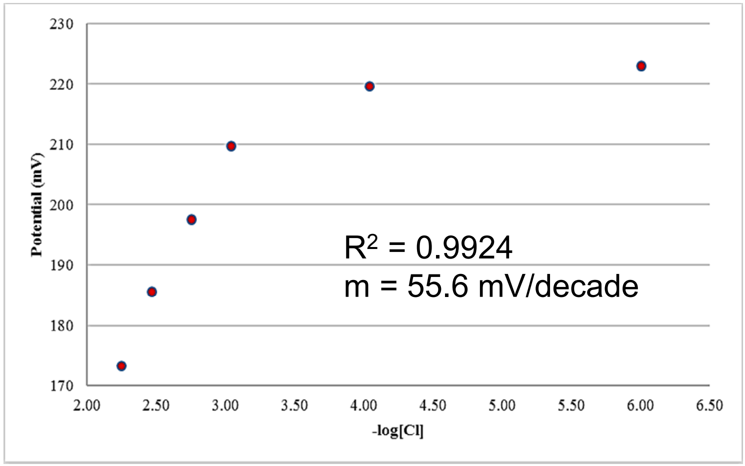
Laboratory Run



Autoclave Runs

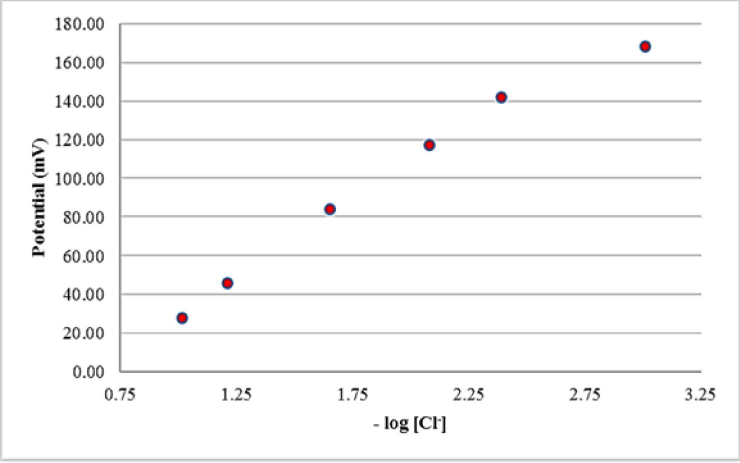


Ambient T & P



70°C and Ambient

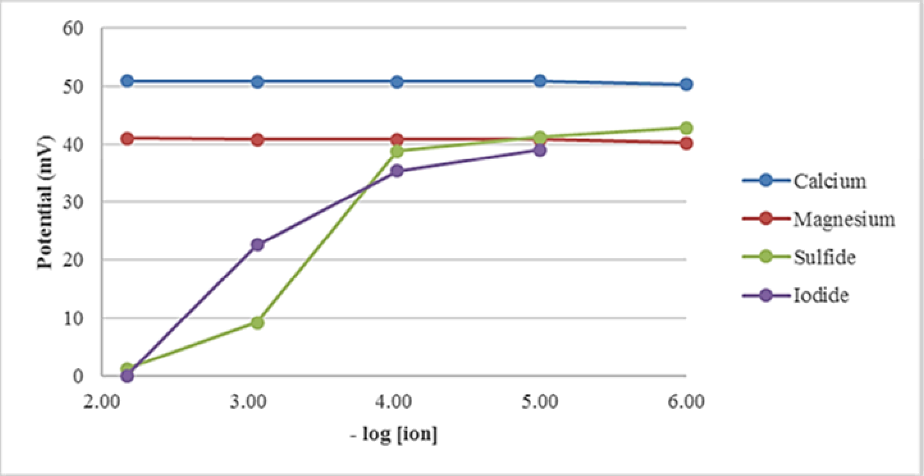
R^2 = 0.9993
m = 82.4 mV/decade



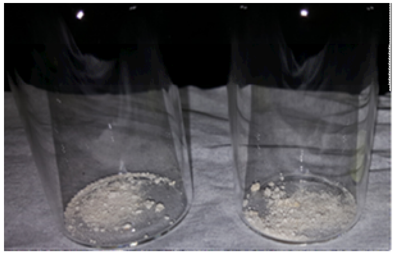
R^2 = 0.983
m = 72.4 mV/decade

200°C & 1279 psi

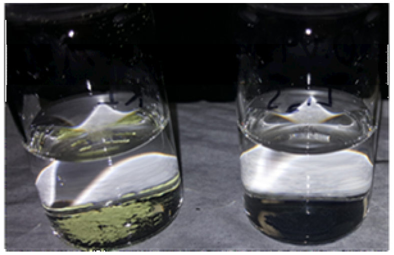
ISE Selectivity



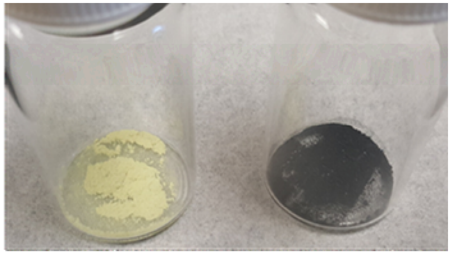
Interfering Ion	Calculated Selectivity Coefficient
S^{2-}	9.50
Ca^{2+}	0.03
Mg^{2+}	0.03
I^-	35.80



AgCl(s)



AgCl(s) in 10 mL of 0.04 M KI & 0.04 M Li_2S



Commercial AgI & Ag_2S

K_{sp}

AgCl = 1.77×10^{-10}

AgI = 8.52×10^{-17}

Ag_2S = 8.0×10^{-51}

ISE Selectivity

Dilution factor	Expected Concentration	Lithium (moles/L)	Potassium (moles/L)	Chloride (moles/L)
964	0.1M KCl	--	0.1043	0.1025
103	0.01M KCl	--	0.0112	0.0101
10	0.001M KCl	--	0.0006	0.0005
103	0.2M LiCl	0.1939	--	0.1999
10	0.02M LiCl	0.0198	--	0.0171
1	0.002M LiCl	0.0022	--	0.0018

Estimated limit of detection for the ions: Li ~ 7.1e^{-5} M; K ~ 1.3e^{-5} M; Cl ~1.4e^{-5} M

Summary & Conclusions

- A downhole tool capable of real-time data collection of P,T, flow rate, and [Cl^-] has been developed to determine optimal geothermal enthalpy environments
- Ruggedized tool specs = Up to 3000 psi and 225° C
- 10^{-1} to 10^{-3} M Cl^- can be linearly measured using an electrochemical sensor composed of 1:1 $Ag_2S/AgCl$, allowing an approximation of steam fraction
- I^- and S^{2-} interfere and exchange for Cl^- on ISM
- Efforts are underway to determine the selectivity coefficients of other ions seen in geothermal brine, lifetime stability of the ISE, and integration of the entire tool for an actual wellbore test.