Injection of Hyper-saline Brine at the Salton Sea Field – Challenges and Benefits

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• The Salton Sea resource is considered one of the largest potential (>2,000 MW) and hottest 250 °C to 370 °C (or 480 °F to 700 °F) water dominated fields in the world.
Salton Sea Background

• Since the reservoir is composed of dry lake bed deposits, the formation fluid contains high levels total dissolved solids (>22 wt %).

• Challenges to development
  • More surface equipment than a typical geothermal power plant to manage solids
  • High scaling rate (>20 inches per year at atmospheric flash vessels)
  • High corrosion rate (chlorides 12.5–18.5 wt. %)
Salton Sea Brine Chemistry

<table>
<thead>
<tr>
<th>Substance</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>15.40</td>
</tr>
<tr>
<td>Sodium</td>
<td>5.27</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.65</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.65</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>0.17</td>
</tr>
<tr>
<td>Iron</td>
<td>0.15</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.14</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.05</td>
</tr>
<tr>
<td>Silica</td>
<td>0.05</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.03</td>
</tr>
<tr>
<td>All Other Materials</td>
<td>&lt;0.03/each</td>
</tr>
</tbody>
</table>

Total Dissolved Solids & Gases 25.69
Typical Injection Fluid
- Moderately high temperature 220 to 230 °F (105 to 110 °C)
- High level of dissolved minerals 30–32% (primarily NaCl, KCl, and CaCl₂)

Design Criteria
- Corrosion
  - Super duplex stainless steel (chloride stress corrosion resistant alloys)
  - Heavy wall carbon steel (requiring periodical replacement)
  - Cement lined carbon steel (primarily for cross country pipelines)
- Temperature
  - Designed for maximum injection pump pressure at elevated temperature
  - Design must address thermal expansion
Injection Well Design

- Cased portion of the well is protected from corrosion by:
  - Super duplex (alloy) casing cemented from the shoe to the surface
  - Carbon steel hang down string (requiring periodical replacement, 24–36 months)

- Due to competency of the formation, open hole completions are utilized
Pipeline Scaling

- The Crystallizer Reactor Clarifier (CRC) and hybrid pH Modification CRC power plants are designed to reduce the silica concentration to near saturation levels
  - Super saturation (scaling tendency) occurs
  - Small amounts of precipitated silica and amorphous iron silicates, typically less than 20 ppm, remain in the spent brine
- Silica inhibitors reduce the scaling rate especially, if the super-saturation levels are low.

- Flange connections usually create scale donuts, because of the turbulence

- Scale adheres to scale
Scale Adhesion and Solids Formation

- Casing and liners, carbon steel is more susceptible than super duplex alloy
- Sand face provides a nucleation point for precipitation of silicates
- Reductions in pressure and temperature (e.g. turbulent zones, wells on a local vacuum) reduce the silica saturation threshold, which can lead to solids precipitation and increases in erosion–corrosion
- Suspended solids are also nucleation points in the brine flow and in the well
Well Scaling & Plugging

- Plugging of the permeable zones poses additional challenges:
  - Sand face and fractures can act as a sieve for suspended particles and pipeline scale
  - Fine particles and clay-like particles can penetrate the sand face and fractures
  - Solids and scale can fill a wellbore and cover all permeable zones
  - Analysis of drill cuttings from injection well re-drills consist of:
    - Layered barite and fluorite, minor anhydrite, copper arsenic sulfides and traces of amorphous silica
Optimized process control in the power plants to minimize:

- Super-Saturation of Silica and Total Dissolved Solids (TDS)
  - Periodical analysis (typically weekly) of injection brine for dissolved silica and TDS
  - TDS levels above 31.5% can lead to chloride precipitation
  - Statistical control trends help to prevent issues and troubleshoot problems

- Suspended Partials (TSS)
  - Periodical analysis (12 hours) of injection brine for suspended
  - Statistical control trend analysis
Carbon steel hung liners are used in a portion of the injection wells. Corrosion–erosion can be estimated on a cumulative injection mass, but for tracking simplicity a life span is assumed at 24 to 36 months.

Operating an injection well on a localized vacuum can exacerbate corrosion–erosion and solids precipitation.

Carbon steel casing fish are common among older injection wells.

Super duplex alloy casing has an estimated life span of 15–20 years.
Injection Pipelines:
- Pressure differentials – normalized to summer rates for long-term performance tracking
- Injection capacity extrapolated to wellhead pressure limit (based on frac gradient) or normalized to a reasonable operating pressure
  - Decline curve analysis

Injection Capacity Forecasts
- Summed injection well capacities that are declined over time
- Compare with seasonal facility injection demand
- Identify deficiencies and plan well interventions

Scale coupons (typical used to determine chemical dosage rates)
Scale Removal – Cleanouts

- **Injection Headers (Pipelines)**
  - Pigging (not currently used)
  - Hydro-blasting (10,000 to 20,000 psi)
  - Replacement of carbon steel sections

- **Injection Wells**
  - Chemical treatments
  - Drilling Rig Interventions
    - Mechanical cleanout with gauge bit
    - Under-ream, expand the open-hole diameter and expose
    - Re-drill of the open-hole section
Benefits

- Pressure support: 75–90% of produced mass is injected back into the reservoir
- Fluid Management: 28.5 million pounds per hour of injection brine
- Mineral recovery
  - Mineral recovery of potash by Pure Oil in the early 1960’s predates electrical generation
  - Potential recovery of minerals, approximations based on existing production and a field wide extrapolation:
    - Lithium Carbonate (Li$_2$CO$_3$) 350,000 metric tons/year
    - Zinc metal (Zn) 100,000 metric tons/year
    - Manganese metal (Mn) 350,000 metric tons/year
    - Potash as KCl 7,500,000 metric tons/year
Questions

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