Cranfield CO₂ Geothermal Field Demonstration

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CO$_2$ Geothermal

- Use CO$_2$ as a working fluid instead of water.
- Take advantage of CO$_2$’s thermodynamic properties to improve system performance.
# Comparing CO₂ with water as a Heat Transmission Fluid

<table>
<thead>
<tr>
<th>Property</th>
<th>Water</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>Powerful solvent for rock minerals, lots of dissolution and precipitation</td>
<td>Non-polar fluid, poor solvent for rock minerals</td>
</tr>
<tr>
<td>Mobility</td>
<td>High viscosity, high density</td>
<td>Low viscosity and moderate density</td>
</tr>
<tr>
<td>Heat transmission</td>
<td>Large specific heat</td>
<td>Small specific heat</td>
</tr>
<tr>
<td>Wellbore circulation</td>
<td>Small compressibility, modest expansivity</td>
<td>Large compressibility and expansivity</td>
</tr>
<tr>
<td>Fluid losses</td>
<td>Expensive and unwanted</td>
<td>Credits for GHG mitigation</td>
</tr>
<tr>
<td>Availability</td>
<td>Widespread, limited in arid regions</td>
<td>GCS key enabling element</td>
</tr>
<tr>
<td>Power plant</td>
<td>Higher capital costs, larger footprint</td>
<td>More compact, lower capital cost</td>
</tr>
</tbody>
</table>
Cranfield CFU-31

- US$36M Investment
- 3 Wells 3.2 km deep
- Injecting CO$_2$ since Dec 2009
- BHT 127° C
- BHP 305 bar
Echogen Power Systems 25 kg/s commercial-scale CO\textsubscript{2} heat recovery system
Geothermal Reservoir Simulation

Tough 2 Simulation: T2Well/ECO2H

<table>
<thead>
<tr>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
</table>
| Conservation of mass and energy           | \[
\frac{d}{dt} \int_M \mathbf{M} \cdot d\mathbf{V}_n = \int \mathbf{F} \cdot n \; d\Gamma_n + \int q^e \; dV_n
\]
| Mass accumulation                        | \[
M^e = \phi \sum \rho_{\beta} X_{\beta}^e
\]
| for each mass component                  |          |
| Mass flux                                | \[
\mathbf{F}^e = \sum \rho_{\beta} X_{\beta}^e \mathbf{u}_{\beta}
\]
| for each mass component                  |          |
| Energy flux                              | \[
\mathbf{F}^e = -\lambda \nabla T + \sum \rho_{\beta} \mathbf{u}_{\beta}
\]
| Energy accumulation                      | \[
M^e = (1 - \phi) \rho_s C_s T + \phi \sum \rho_{\beta} S_{\beta} U_{\beta}
\]
| Porous media                             | \[
\mathbf{u}_{\beta} = -k_{s,\beta} \mu_{\beta} (\nabla P_{\beta} - \rho_{\beta} \mathbf{g})
\]
| Phase velocity                           | \[
\mathbf{u}_{\alpha} = C_0 \frac{\rho_{\alpha}}{\rho_n} u_n + \frac{P_n}{\rho_n} u'_n
\]
| Production phase velocity                 | \[
u_s = \frac{(1 - S_{\alpha} C_0) \rho_{\alpha}}{1 - S_{\alpha}} u_n - \frac{S_{\alpha} \rho_{\alpha}}{(1 - S_{\alpha}) \rho_n} u'_n
\]

We solve the 2-phase momentum equation using the Drift-flux model (DFM)

- one integrated system
- two different subdomains
- viscous flow in the wellbore governed by the 1D momentum equation
- 3D flow through porous media in the reservoir is governed by a multiphase version of Darcy’s Law.
- Connected at well/reservoir interface
30-yr simulation results – Strong thermosiphon

<table>
<thead>
<tr>
<th>Mass flow rate</th>
<th>5 kg/s</th>
<th>25 kg/s</th>
<th>75kg/s</th>
<th>100kg/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellbore feature</td>
<td>7 in</td>
<td>7 in*</td>
<td>4 in</td>
<td>7 in</td>
</tr>
<tr>
<td>Injection WHP (MPa)</td>
<td>7.36</td>
<td>6.60</td>
<td>6.72</td>
<td>6.53</td>
</tr>
<tr>
<td>WHT (°C)</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Energy (MW)</td>
<td>2.85</td>
<td>2.96</td>
<td>2.89</td>
<td>15.01</td>
</tr>
<tr>
<td>Production WHP (MPa)</td>
<td>14.46</td>
<td>16.28</td>
<td>15.41</td>
<td>14.50</td>
</tr>
<tr>
<td>WHT (°C)</td>
<td>64.06</td>
<td>106.56</td>
<td>81.83</td>
<td>88.95</td>
</tr>
<tr>
<td>Energy (MW)</td>
<td>3.34</td>
<td>3.84</td>
<td>3.58</td>
<td>18.59</td>
</tr>
</tbody>
</table>

* No heat exchange in wells
Instrument F3 well with fiber-optic DTS sensor and quartz pressure temperature sensors.
Surface Equipment of Operation and Monitoring of CO$_2$ Thermosiphon

Equipment at F3

Equipment at F1
Flow Iron – Producer to Injector
Heatric Exchangers for Cooling CO$_2$
Operations control center and systems monitoring
Venting Operations – bring up warm CO$_2$
Operational Issues – producing solids and other items

CO₂ Hydrates

Uncooperative Winds

Plugged Filter
Data Collected

• DTS fiber-optic temperature logs of F2 and F3 well
• Quartz pressure and temperature from the reservoir interval in F2 and F3
• Fluid pressure and temperature at the outlet of the F3 production tubing
• Differential pressure across the 100 μ filter unit
• Emerson Micromotion Coriolis measurement of the fluid mass flux rate and density
• Pressure and temperature at the Coriolis flowmeter exit
• Pressure and temperature downstream of the recirculation pressure control valve
• Pressure and temperature at the outlet of the heat exchangers and inlet to F1
• Set point for vent valve
• Set point for pressure control valve
Conclusions

- The thermosiphon was set up but was not self-sustaining
- Water production was higher than predicted
- A detailed analysis of the data will be required to understand the field observations
Acknowledgments

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Thanks for your attention. Any questions?