Design Requirements for Commercial Sedimentary Geothermal Projects

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Power Plays: Geothermal Energy in Oil and Gas Fields
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## Geothermal vs. Petroleum – a Comparison

<table>
<thead>
<tr>
<th>Petroleum</th>
<th>Geothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td><strong>Temperature</strong></td>
</tr>
<tr>
<td>300-350°F is “Hot” (150-175°C)</td>
<td>300-650+°F (150-350+°C)</td>
</tr>
<tr>
<td><strong>Flow Rates</strong></td>
<td><strong>Flow Rates</strong></td>
</tr>
<tr>
<td>5,000 bpd/well is “High Flow” (150 gal/min per well)</td>
<td>50,000 bpd/well is <em>average</em> (1,500 gal/min per well)</td>
</tr>
<tr>
<td>Vertical and Long Reach Horizontal Onshore/Offshore</td>
<td>Vertical/Deviated Onshore</td>
</tr>
<tr>
<td>5”-7” diameter production interval</td>
<td>8”-12” diameter bottom hole</td>
</tr>
<tr>
<td><strong>Production Profile/Timeframe</strong></td>
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</tr>
<tr>
<td>High Initial Flow (months) Declining Rate (years)</td>
<td>Constant Production 20-30+ Years</td>
</tr>
<tr>
<td><strong>Lithology</strong></td>
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</tr>
<tr>
<td>Sedimentary</td>
<td>Volcanic/Intrusive/Metamorphic</td>
</tr>
<tr>
<td><strong>Facies</strong></td>
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</tr>
<tr>
<td>Stratigraphic/Structural</td>
<td>Complex Fault-Dominated</td>
</tr>
<tr>
<td><strong>Recovered Product &amp; Value</strong></td>
<td><strong>Recovered Product &amp; Value</strong></td>
</tr>
<tr>
<td>Petroleum (Oil &amp; Gas)</td>
<td>Heat (Hot Water)</td>
</tr>
<tr>
<td>~$40/barrel oil</td>
<td>~$0.25/barrel hot water</td>
</tr>
</tbody>
</table>
Temperature is important, but is not enough...

Need both Temperature AND Flow Rate for commercial power generation:

Electricity Generation vs. Temperature

Flow Rate Requirements vs. Temperature

Adapted from Augustine and Falkenstern (2014), SPE-163142
Which is a better sedimentary geothermal target?

- Areas A (red) and B (blue) both show elevated temperatures
- Area A has higher temperature...
- ...but Area B has higher porosity ($\phi$) and permeability ($k$): $\phi \sim \log(k)$
- Area B is selected due to its higher porosity (higher permeability)

Based on static reservoir model for Wattenberg Field built from well logs (Zhou, CSM Masters Thesis, 2016)
Sedimentary Geothermal Reservoir Requirements

**Temperature**
- Resource quality
- Higher temperature = more power potential

**Reservoir Volume**
- Resource available
- Must be large enough to maintain production for project lifetime
- Areal Extent x Pay Zone Thickness

**Flow Capacity** \((kh)\)
- Resource recoverability
- Amount of geofluid that can be produced from well
- Formation permeability \((k)\) and pay zone thickness \((h)\)

Utility-Scale Electricity Generation
Sedimentary Geothermal Doublet – Analytic Model

• **Time for thermal breakthrough** at production well (Gringarten, 1979)

\[
\Delta t = \left[ \phi + (1 - \phi) \frac{\rho_r C_{p,r}}{\rho_w C_{p,w}} \right] \frac{\pi D^2 h}{3} \frac{1}{Q}
\]

• **Pressure difference** between injection and production wells (Gringarten, 1979; Muskat, 1939)

\[
\Delta P = \frac{\mu Q}{\pi k h} \ln \left( \frac{D}{r_{well}} \right)
\]

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity, ( \phi )</td>
<td>0.15</td>
</tr>
<tr>
<td>Reservoir thickness, ( h )</td>
<td>50 m</td>
</tr>
<tr>
<td>Rock heat capacity, ( \rho_r C_r )</td>
<td>2,770 kJ/m(^3)/°C</td>
</tr>
<tr>
<td>Water heat capacity, ( \rho_w C_w )</td>
<td>3,860 kJ/m(^3)/°C</td>
</tr>
<tr>
<td>Water viscosity, ( \mu_{avg} )</td>
<td>2.18e-4 Pa-s</td>
</tr>
<tr>
<td>Well radius, ( r_{well} )</td>
<td>0.108 m (8.5” diam.)</td>
</tr>
<tr>
<td>Reservoir lifetime, ( \Delta t )</td>
<td>30 years</td>
</tr>
</tbody>
</table>
Reservoir Lifetime and Well Spacing

- Well spacing on the order of 4,000-6,000 ft (1-2 km) required for doublet system for production well flow rates typically found at conventional hydrothermal power plants (independent of reservoir permeability)

\[ \Delta t = \left[ \phi + \left(1 - \phi \right) \frac{\rho_r C_{p,r}}{\rho_w C_{p,w}} \right] \frac{\pi D^2 h}{3 \frac{Q}{Q}} \]

Assuming reservoir height of \( h = 50 \text{ m} \) (165 ft)

Adapted from Augustine (GRC 2014)
Well Productivity

- Average required reservoir transmissivity/flow capacity vs. well productivity for a range of well spacings with 30-year reservoir lifetime
- Productivity index range studied requires reservoir permeabilities of hundreds to thousands of mD for the specified system performance

Assuming reservoir lifetime of 30 years

\[
\frac{Q}{\Delta P} = \frac{\pi k h}{\mu} \left( \ln \left( \frac{D}{r_{well}} \right) \right)^{-1}
\]

Adapted from Augustine (GRC 2014)
Summary – “Ball Park” Reservoir Requirements

1. Well-doublet system reservoirs with life times of 30 years and well flow rates of 25,000-50,000 bpd (~50-100 L/s) require a well spacing on the order of 3,000-6,000 ft

2. Relatively high permeabilities, on the order of hundreds or thousands mD, required for commercially-viable vertical well doublet systems

(from Kirby, 2012)
Can Reservoir Performance Be Improved?

1. Vertical wells doublet with hydraulic fractures
2. Horizontal wells with open-hole completions
3. Horizontal wells with longitudinal fractures
4. Horizontal wells with multi-stage hydraulic fractures

- Studied impact of well-configurations on well productivity
- Found that use of horizontal wells and fracturing can increase well productivity by factor of 3-5

Adapted from Cho et al. (Stanford 2015)
Summary

1. Need to speak the same language
2. Temperature is important, but is not the only factor
   - Need large flow rates (ex. ~80,000 bpd @ 300°F for ~5 MW<sub>e</sub>) ➔ High reservoir permeability (100’s to 1,000’s mD) and thickness
   - Need long system lifetime (20-30 years) ➔ Large reservoir and well spacing (several thousand feet)
3. Petroleum industry has knowledge and expertise to find and develop these systems
   - In-depth knowledge of potential sedimentary basins
   - Improve reservoir performance with well design and enhancement techniques
Questions?

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Related Publications


Additional References