Ways to Minimize Water Usage in Engineered Geothermal Systems

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Engineered geothermal systems are sited in locations lacking one or more advantageous features: porous rock, high temperatures, abundant subsurface water.
Water Use in Engineered Geothermal Systems

Drilling
- Hydraulic fracturing

Production
- Open system – water is pumped and discharged at the surface
- Closed system – pumped water is reinjected
- Heat rejection at power station

<table>
<thead>
<tr>
<th>Utility type</th>
<th>Average Water Use (L·(MWh)^-1)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>47000 (evaporation from reservoirs)</td>
<td></td>
</tr>
<tr>
<td>Geothermal (hydrothermal)</td>
<td>5400 (geyser flash evaporation)</td>
<td></td>
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<tr>
<td>Nuclear thermal</td>
<td>3200 (cooling)</td>
<td></td>
</tr>
<tr>
<td>Coal (conventional)</td>
<td>3000 (cooling)</td>
<td></td>
</tr>
<tr>
<td>Concentrated solar</td>
<td>2900 (cooling)</td>
<td></td>
</tr>
<tr>
<td>Gas fired (conventional)</td>
<td>2300 (cooling)</td>
<td></td>
</tr>
<tr>
<td>Integrated gas combined cycle (IGCC)</td>
<td>880 (cooling)</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Solar photovoltaics</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Merson 2006 – Report to Congress
Subsurface Flow Affects Efficiency

- Efficiency related to energy to pump fluid through rock
- Depends on rock permeability
- Depends on heat recharge
- Dynamic effect
  - Pulsed fluid flows
  - Long term fluctuations, seasonal

Tomographic scan of sample from The Geysers, CA
Multiscale Study of Rock Porosity

- Nanoscale imaging from neutron scattering
- X-ray microtomography
  - 3-D images
- Analyze using correlation analysis to give “connected porosity”
- Larger scale by sampling throughout play
- Developing methods to avoid bias in results

Bedding evident in shale sample
Extension to Water/Rock Interactions

- Working to develop a model relating connected porosity to permeability
- Needs to account for the properties of the rock
  - Heterogeneity using fractal analysis (Li & Horne 2009)

- Needs to account for the properties of the fluid
  - Salinity
  - Density
  - Viscosity
  - Fluid/rock chemistry
  - (Franke and Thorade 2010)

- Long term variation in heat transport, rock microstructure

![Images of igneous and sedimentary rocks](images.jpg)
Cooling Water and Advanced Power Cycle Development

- Traditional geothermal has efficiency ~12%
- EGS has lower efficiency because source temperature <200°C
- Evaluated Organic Rankine and supercritical cycles with mixtures of CO₂ and refrigerants
- Evaluated the effect of cooling temperature on efficiency
Thermodynamic Modeling of Power Cycles

• Set parameters
  – Source temperature
  – Coolant temperature
  – Working fluid composition (and properties)
  – Pumping speed
  – Pressure drop
  – Cycle pressure ratio

• Varied areas of heat exchangers iteratively (closed system) to get mathematical convergence

• Calculated cycle efficiency

\[ \eta_T = \frac{W_{net}}{Q_{in}} = \frac{W_{Turb} - W_{Pump}}{Q_{in}} \]

Sabau et al. AMSE 2011
Efficiency Gains from Supercritical Working Fluids

- Efficiency more strongly correlated with condenser size than evaporator size
- Tradeoff between performance of condenser and recuperator
- With condensation, saw 13.5% maximum efficiency
- For air cooling, need higher critical point fluid running in supercritical Brayton cycle, giving maximum efficiency of ~11% from these calculations
Experimental Study of Supercritical Mixtures at Sandia National Laboratories

Measured:

- Compressor performance
- Mixture properties
  - CO₂ + n-butane
  - CO₂ + SF6
  - CO₂ + helium
  - CO₂ + neon
- Materials compatibility
Study of New Supercritical Mixtures

Equation of State

Viscosity

$\eta, \lambda$ are proportional to density, $\rho$, molecular volume, $b$, and radial distribution function, $\chi$

Experiment

Modeling

$\frac{P}{\rho k T} = 1 + \frac{(b_k - a)}{1 + 0.227 \rho \Gamma} + \frac{a \rho}{1 - \Gamma \rho}$

Molecular dynamics gives $B_2(T)$, $\alpha(T)$, $\beta(T)$

Measurements $\rightarrow$ Cubic EOS

EOS from stat mech

$\rightarrow$ Measurements
Areas for Further Investigation in Geothermal Water Use

- **Subsurface water use**
  - Develop *in-situ* neutron scattering analysis of fluid in pores
  - Study changes in water flow, heat flow, water chemistry over time
  - Evaluate competing factors in siting, such as depth versus porosity, number of wells

- **Surface water use**
  - Determine effect of impurities for reuse of flowback water
  - Study effect of impurities in working fluids
  - Develop efficient heat exchanger design
Water Use Can Be Reduced by Planning and Optimization

- Coordinate with utilities, municipalities, regulators
- Determine engineering and regulatory requirements for water reuse
- Take advantage of water recycle opportunities
- Understand complete water cycle and account for losses
- Geothermal won’t increase unless solutions found for water use

Energy Generation from Renewables

![Graph showing energy generation from renewables from 2003 to 2009](chart.png)

www.eia.gov
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  • Andy Kercher
  • Kevin Qualls

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