Use of convection for the enhancement of energy well performance?

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Ground-stored heat

- Renewable energy available for the heating and cooling of buildings.

- Definition: Low-enthalpy (< 30°C) energy which is renewed via:
  a) Solar irradiation
  b) Geothermal processes (radioactive decay, vertical heat flow)

Figure 1. Heat flows above and below ground (mod. Banks, 2008).
Ground-stored heat

Figure 2. Temperature variation within one year at Elverum waterworks (NGU).
Ground-stored heat

- (Partly) renewable energy
- Heat pump technology
- Different technical solutions
  a) Open system
  b) Closed system

Figure 3. Sketches of open and closed ground-stored heat systems (NGU).
Research question

- How important is natural convection in an energy well for the performance?
  → Video of natural convection

- Can artificial convection enhance the performance of an energy well?

Figure 4. Convection above the warm Trondheimsfjord in winter 2010/2011.
Thermal response test (TRT)

Figure 5. Setup of a thermal response test (TRT; Gehlin 2002).
MIR-TRT

Figure 6. Temperature development during a first standard multi-injection rate TRT (MIR-TRT, see Gustafsson & Westerlund 2010).
Figure 7. Setup of a MIR-TRT with artificial convection (left, Vistnes 2011) induced with a groundwater pump (right).
MIR-TRT with artificial convection

→ Video of forced convection

Figure 8. Picture of the equipped well.
MIR-TRT with artificial convection

Figure 9. Temperature development during a second MIR-TRT with pumping of groundwater.
Models and calculations

- Effective thermal conductivity, $\lambda_{\text{eff}}$ and borehole resistance, $R_b$:
  - Infinite line-source theory (ILS, parameter estimation, see Ingersoll et al. 1948)
  - Hellström’s 2D numerical model (see Hellström 2001)

- Required borehole lengths:
  - EarthEnergyDesigner (EED, black box model, Eskilson et al. 2000)
Table 1. Effective thermal conductivity, $\lambda_{\text{eff}}$ and borehole resistance, $R_b$ in the case of natural convection:

<table>
<thead>
<tr>
<th>Heat input rate</th>
<th>25 [W m$^{-1}$]</th>
<th>45 [W m$^{-1}$]</th>
<th>64 [W m$^{-1}$]</th>
<th>83 [W m$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{\text{ILS}}$ [W m$^{-1}$K$^{-1}$]</td>
<td>4.11</td>
<td>3.98</td>
<td>4.67</td>
<td>4.22</td>
</tr>
<tr>
<td>$\lambda_{\text{Hell}}$ [W m$^{-1}$K$^{-1}$]</td>
<td>4.47</td>
<td>4.16</td>
<td>4.96</td>
<td>4.32</td>
</tr>
<tr>
<td>$R_{b,\text{ILS}}$ [m K W$^{-1}$]</td>
<td>0.110</td>
<td>0.090</td>
<td>0.090</td>
<td>0.070</td>
</tr>
<tr>
<td>$R_{b,\text{Hell}}$ [m K W$^{-1}$]</td>
<td>0.115</td>
<td>0.093</td>
<td>0.097</td>
<td>0.079</td>
</tr>
</tbody>
</table>
Example: Swedish single-family house

Figure 10. Building load profile of a Swedish single-family house used for a simulation of required borehole lengths (Spitler et al. 2010).
Natural vs. artificial convection

Figure 11. Required borehole lengths for the single house depending on the heat input rate for the MIR-TRTs with and without pumping of groundwater.
Summary and future work

- Naturally occurring convection increases the performance of an energy well.
- Forced convection seems to increase the performance further (see also Kharseh & Ossiansson 2011).
- Forced convection may be an option in well fields with borehole thermal energy storage.
- Efficiency studies should be performed in well fields that are in operation (with groundwater pumps installed in the wells).
References


Thanks for your attention!