Convective Heat Transfer in a Geothermal Heat Pump

1. Introduction

Geothermal heat pumps, also called Ground source heat pumps, offer an attractive option for heating and cooling residential and commercial buildings.

Figure 1.1. Schematic of a Typical Vertical Closed-Loop, Ground-Coupled Heat Pump
Convective Heat Transfer in a Geothermal Heat Pump

2. Governing Equations

1. \(-\nabla \cdot (\eta (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) + \rho (\mathbf{u} \cdot \nabla) \mathbf{u} + \nabla p = 0\)
\(\nabla \cdot \mathbf{u} = 0\)

2. \(\nabla \cdot (-k \nabla T + \rho C_p T \mathbf{u}) = 0\)

3. \(\mathbf{u} \cdot \mathbf{n} = u_0\)
\(T = T_0\)

4. \(q \cdot \mathbf{n} = \rho C_p T \mathbf{u} \cdot \mathbf{n}\)

5. \(\mathbf{u} = 0\)
\(T = T_1\)

Figure 2-1: Sketch of geothermal heat exchanger.
3. Formulation

**Thermal Properties: Water**
- $\eta = 1.00 \times 10^{-3}$ Dynamic Viscosity (kg m$^{-1}$ s$^{-1}$)
- $\rho = 1.00 \times 10^{3}$ Density (kg)
- $C_p = 4.20 \times 10^{3}$ Heat Capacity (J kg$^{-1}$ K$^{-1}$)
- $k = 0.6$ Thermal Conductivity (W m$^{-1}$ K$^{-1}$)
- $T_{in} = 301.8$ Temperature entering (K)
- $T_w = 284.3$ Temperature wall (K)

**Thermal Properties: PVC**
- $\eta = 1.00 \times 10^{0}$ Dynamic Viscosity (kg m$^{-1}$ s$^{-1}$)
- $\rho = 1.76 \times 10^{3}$ Density (kg)
- $C_p = 3.20 \times 10^{2}$ Heat Capacity (J kg$^{-1}$ K$^{-1}$)
- $k = 0.1$ Thermal Conductivity (W m$^{-1}$ K$^{-1}$)

**Thermal Properties: Concrete**
- $\eta = 1.00 \times 10^{0}$ Dynamic Viscosity (kg m$^{-1}$ s$^{-1}$)
- $\rho = 2.30 \times 10^{3}$ Density (kg)
- $C_p = 1.26 \times 10^{3}$ Heat Capacity (J kg$^{-1}$ K$^{-1}$)
- $k = 1.8$ Thermal Conductivity (W m$^{-1}$ K$^{-1}$)

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**Incompressible Navier-Stokes**

<table>
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<tr>
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<th>1</th>
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<th>3</th>
<th>4</th>
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<tr>
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<td>I/O</td>
<td>IN/P</td>
<td>NS IN/P</td>
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**Notes:**
- S/S: Slip/Symmetry
- I/O: Inflow/Outflow Velocity
- N/P: Normal flow/Pressure
- NS: No-Slip

**Convection and Conduction**

<table>
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<tbody>
<tr>
<td>Type</td>
<td>T</td>
<td>T</td>
<td>CF</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
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<td>$T_{in}$</td>
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</tbody>
</table>

**Notes:**
- T: Thermal Insulation
- T: Temperature
- CF: Heat Flux
- CF: Convective Flux
4. Solution

From top to bottom:
Convection decreases as velocity increases.
Convective Heat Transfer in a Geothermal Heat Pump

5. Validation

Load Across Geothermal Wells 59.7 MBTUH
6.0 tons

positive values indicate heat removed from building

Current Supply Temperature 79.1 °F

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<th>Today</th>
<th>Month-to-Date</th>
<th>Year-to-Date</th>
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<td>Highs</td>
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<td>3:36 PM</td>
<td>6:14 PM</td>
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<tr>
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<tr>
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<td>74.9 °F</td>
<td>70.1 °F</td>
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<tr>
<td>7:01 PM</td>
<td>7:17 AM</td>
<td>6:54 AM</td>
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Current Return Temperature 79.6 °F

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<th>Year-to-Date</th>
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</thead>
<tbody>
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<td>Highs</td>
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<tr>
<td>93.0 °F</td>
<td>93.0 °F</td>
<td>100.6 °F</td>
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<td>1:44 PM</td>
<td>1:00 PM</td>
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<td>7:12 PM</td>
<td>7:12 AM</td>
<td>11:18 PM</td>
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Recorded Since 7:52 PM 12/23/2005
Convective Heat Transfer in a Geothermal Heat Pump

6. Parametric Study

Old Economy - Visitors Center - Water Side Schematic

Symbols Legend
CH Cabinet Heater
RHC Reheat Coil
DTC Dual Temperature Coil

second floor
AC-7 AC-5 HP-8 AC-4
DPI

DP1 actual 7.0 °F
setpoint 14.0 °F

DP2 actual 5.0 °F
setpoint 13.0 °F

Water furnace Liebert
HP-1 thru HP-9 AC-1 thru AC-7

first floor
HP-7 HP-6 HP-5 HP-4

basement
UH-1 RHC-1 DTC-1 RHC-2 RHC-3 RHC-4 UH-2 VU-1

Temperature Monitoring Points
Unit Name Supply Temp ST Setpoint Return Temp
WHP-1 71.0 100.0 71.1
WHP-2 80.2 100.0 79.9
glycol 79.0 NA 60.0

Pump 1 & 2 Summary
Lead Pump 2
Pump 1 s/s Disabled
Pump 1 status OFF
Pump 2 s/s Disabled
Pump 2 status OFF
VFD 0 % speed
Glycol Flow Rate 241 gpm

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7. Conclusions

1. Varying flow has more impact in ground source heat transfer systems than varying temperature (Tin)

2. Flow is varied in real systems using variable speed drives coupled to the building load profile through building automation control systems.

3. Ability to visualize remote or hidden processes lead to better understanding of systems.