Analysis of Heat Transfer in a Geothermal Cooling System

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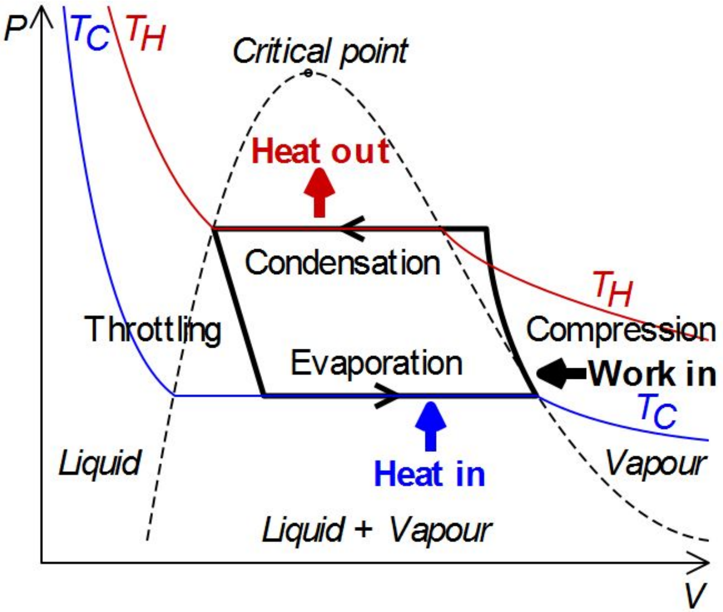
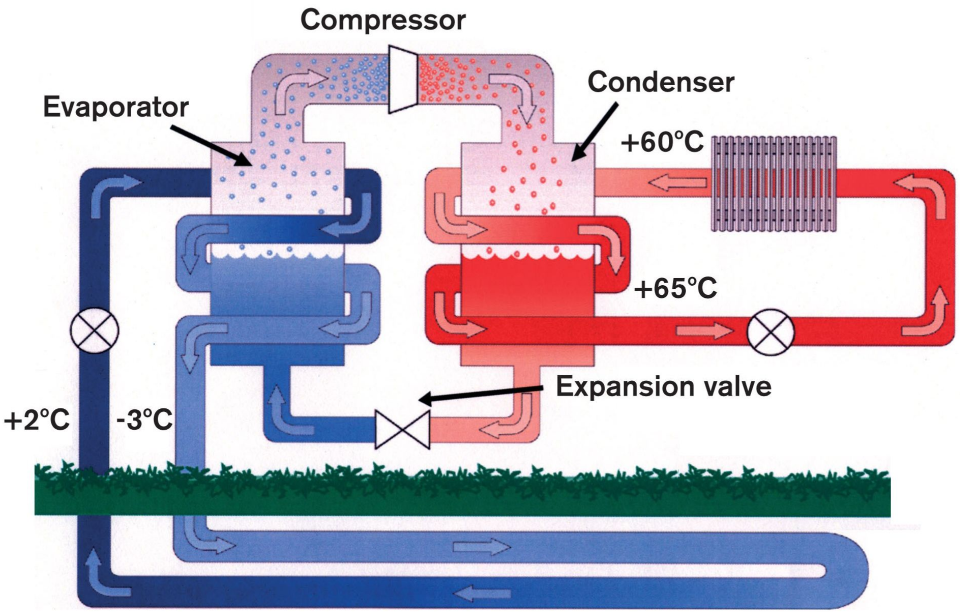
Background

- Normal refrigeration / heat pump cycle
- Functions on the vapor compression cycle from thermodynamics
- Summer time - Heat is removed from the house and expelled outside
- Winter time - Heat is absorbed from the underground soil environment and added inside the house



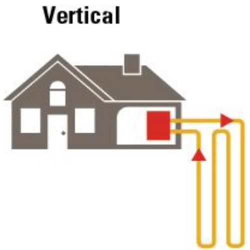
Geothermal Heat Pump

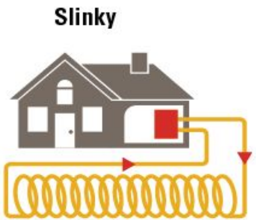
- Geothermal pump replaces a section of the normal heat pump cycle with a heat exchanger
- A secondary loop acts as either a “cold sink” or “hot sink”
- The basic principle is to use the constant temperature ground to cool or heat year around



Problem Formulation

- Loops run through the ground with a water antifreeze fluid being pumped through it
- Different systems have different layouts:
  - Vertical
  - Horizontal
  - Slinky
- Vertical is great for small areas but both horizontal and slinky have cheaper install rates





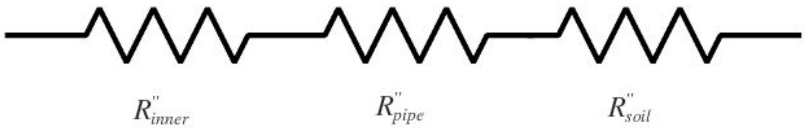
Problem Formulation

- Thermal circuit can be constructed
- For working fluid convection coefficient can be calculated
- Radial heat transfer through pipe wall and through the ground (k=0.461)
- Modeled as constant temperature ground with little variance along the pipe
- Assumed that soil becomes constant temperature after a foot (k=1.25)

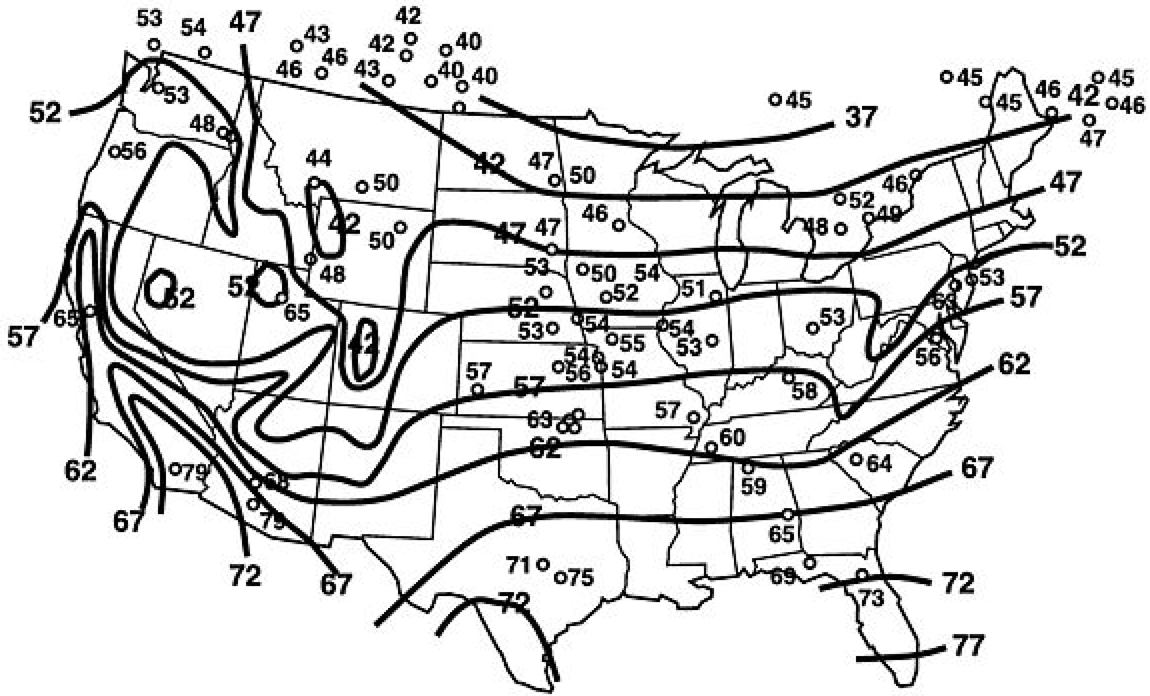
$$Nu_D = \frac{(f/8)\,(Re_D - 1000)\,Pr}{1 + 12.7(f/8)^{1/2}\left(Pr^{2/3} - 1\right)}$$

$$Nu_D = \frac{hD_h}{k} \rightarrow h = \frac{Nu_D k_{water}}{D_h}$$

$$R_{total} = \frac{1}{hA_s} + \frac{ln(r_o/r_i)}{2\pi L k_{pipe}} + \frac{ln(r_\infty/r_o)}{2\pi L k_{soil}}$$



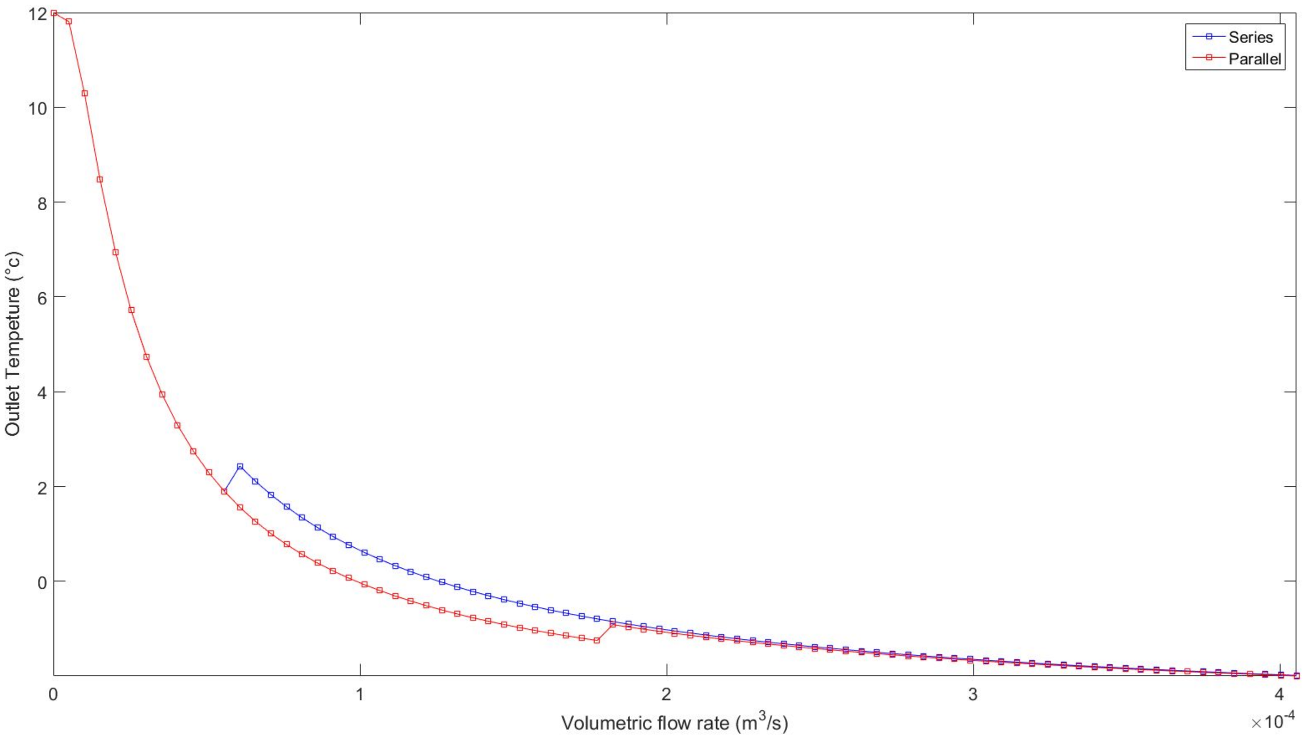
Type	Thermal Conductivity (W/mK)
HDPE Pipe	0.461-0.502
PVC Pipe	0.147-0.209
CPVC Pipe	0.133-0.144
Sandy Soil (Dry)	0.30
Sandy Soil (Wet)	2.20
Clay Soil (Dry)	0.25
Clay Soil (Wet)	1.58



Measured in Fahrenheit

Results

- 1” HDPE Pipe
- Ground Temp 12°C
- Inlet Temp -3°C
- Series - 60m
- Parallel - 3x20m



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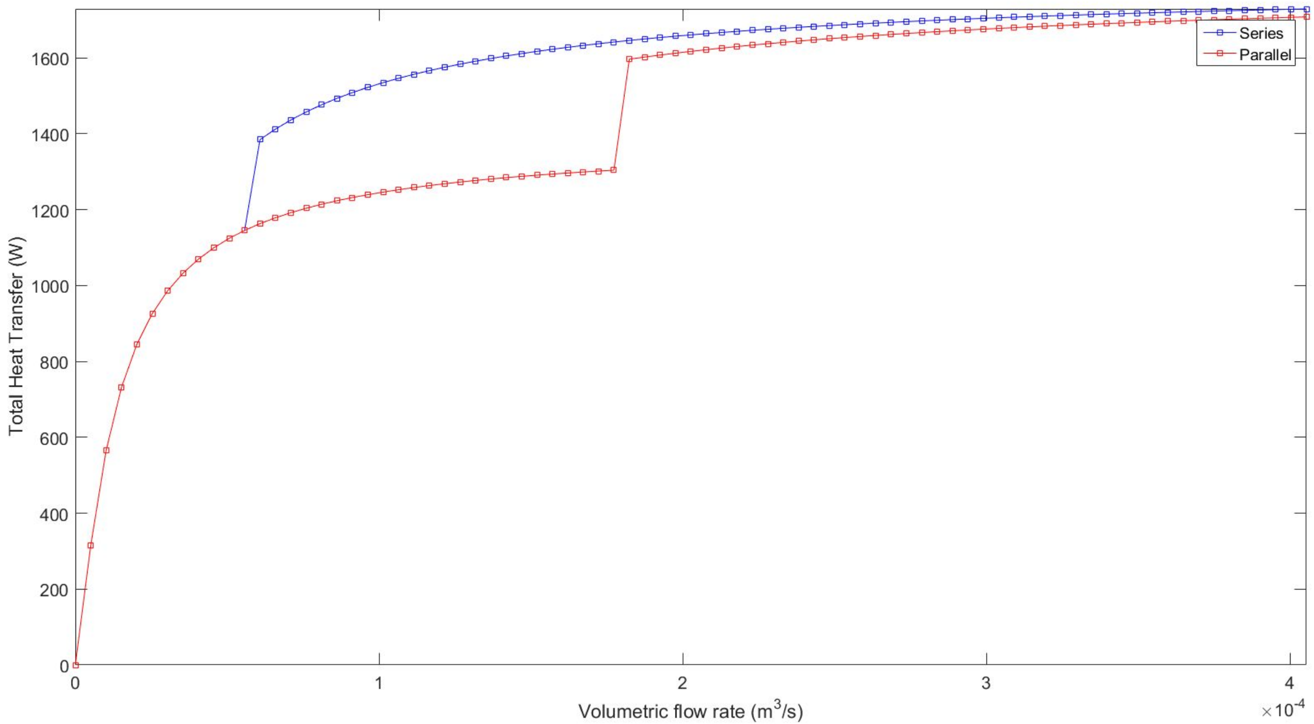

Summary

- Series configuration has better heat transfer per length
- Parallel limits the transition to turbulence
- Choice of pipe with good conduction coefficient is important
- When sizing a system the total heat transferred can be used to judge the length of pipe needed
- Parallel offers the ability to use a smaller circulation pump
- Soil thermal resistance is the largest limiting factor

Questions?