Arizona State University

Fluidaptic, LLC

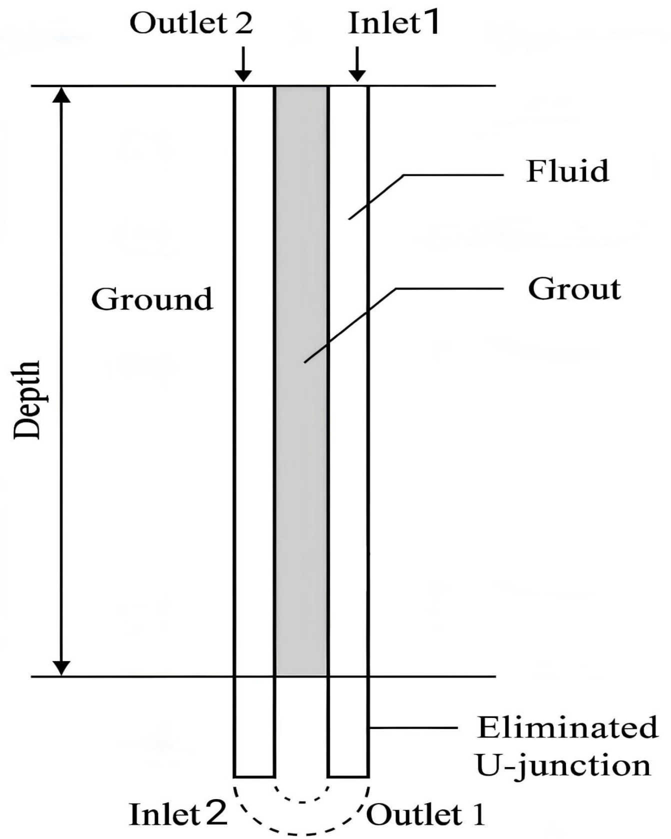
Thermal Short-Circuiting in Geothermal Heat Exchangers

Objective Of the Project

To study thermal short-circuiting in geothermal heat exchangers, a condition where heat from the outlet loop flows back toward the inlet, reducing system efficiency.

This project aims to:

- Understand what causes short-circuiting.
- Analyze how it affects heat transfer performance.
- Investigate how design factors, especially shank spacing, influence the issue.
- Explore ways to reduce thermal interference between the pipes.
- Improve overall system efficiency using optimized layouts and flow strategies.



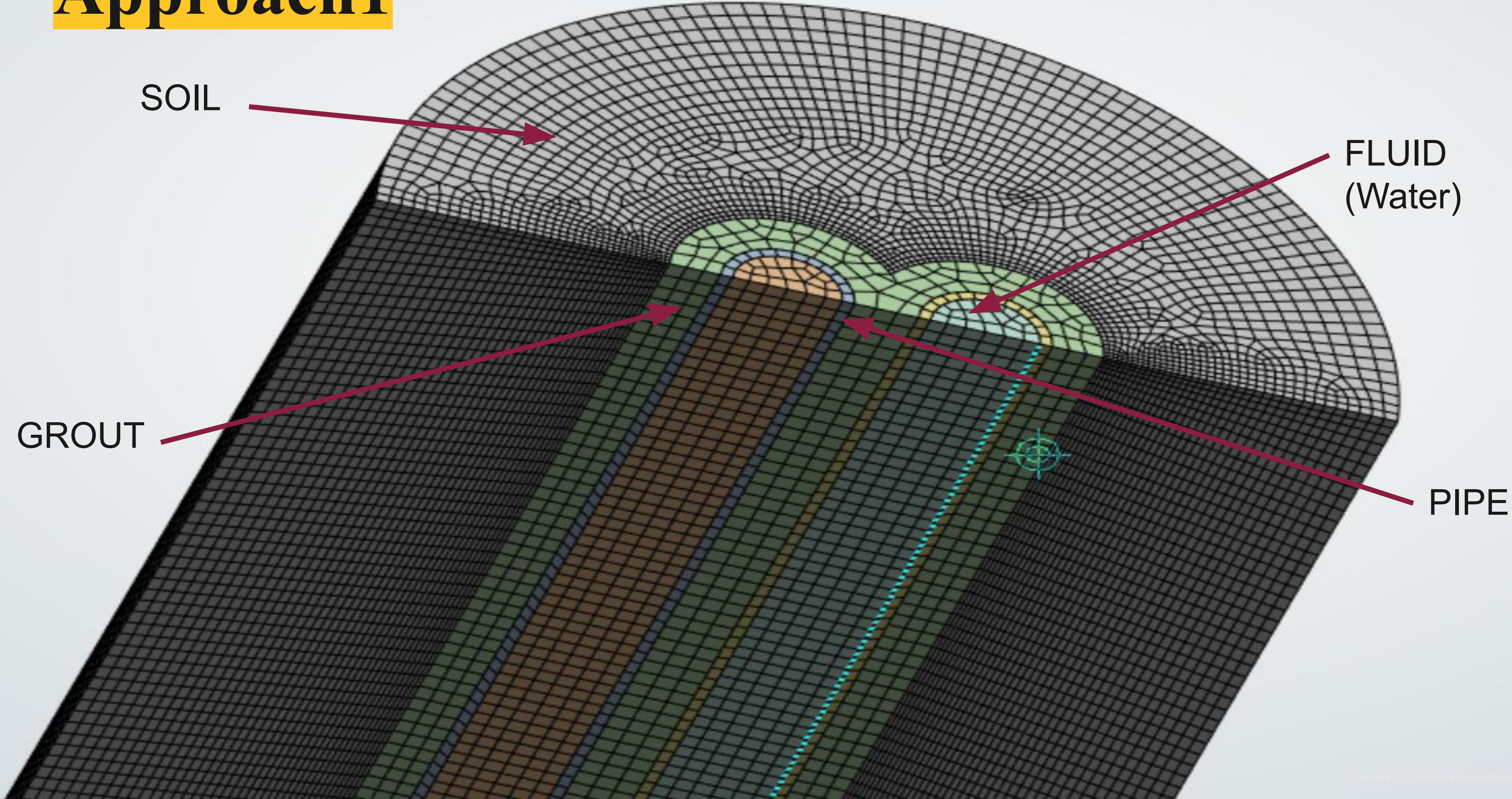
Model Setup

- Assumptions:
  - Modeling in Steady State
  - HDPE Tube 1.315” OD x 1.077” ID
  - Constant ground temperature > 20 ft
  - Constant depth of 100ft
  - Water working fluid
  - Counter Flow in the two tubes
  - Barely turbulent flow
  - Based Soil Properties and Temperatures in Minnesota
  - 0.5” radius bentonite grout surrounding HPDE tube
  - Approach 1(ignoring U-return)
  - Approach 2 (including U-return)
  - No Boreholes in the system

- Model Parameters

Parameter	Values [Units]
Soil Thermal Conductivity [1]	1.435 [W/m K]
Bentonite Grout Thermal Conductivity [2]	1.65 [W/m K]
HDPE Tubing Thermal Conductivity	0.481 [W/m K]
Water Mass Flow Rate	0.142 [kg/s]
Soil Temperature	283 [K]
Water Inlet Temperature	315 [K]

Approach1



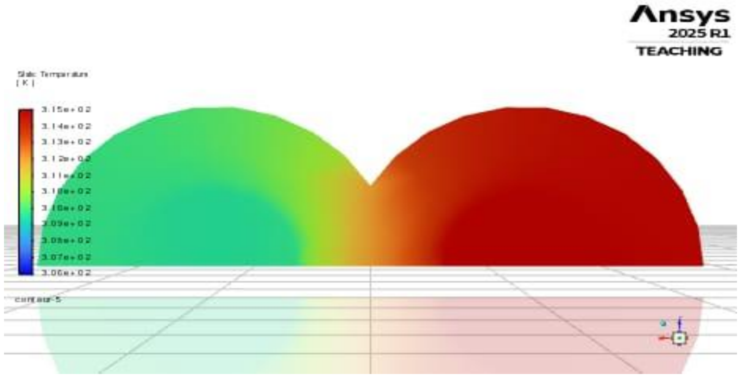
Ansys Fluent Model

- Various geometries created by changing tube spacing between 2 and 15 inches
- Amount of short circuiting determined by change in outlet temperature of fluid with change in tube spacing
- Constant mass flow rate and constant pressure

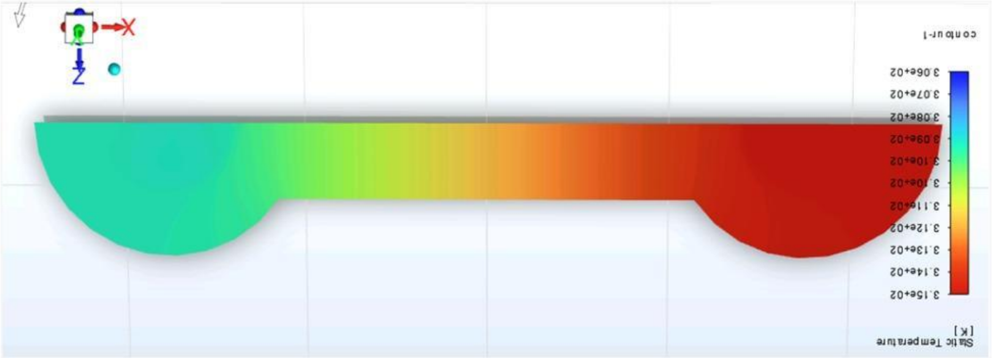
Tube Spacing	Inlet Temperature[K]	Outlet Temperature [K]
2”	315	309.42
5.5”	315	309.42
6.5”	315	309.3
10”	315	309.21
15”	315	303.67

Ansys Fluent Results

- 2” model

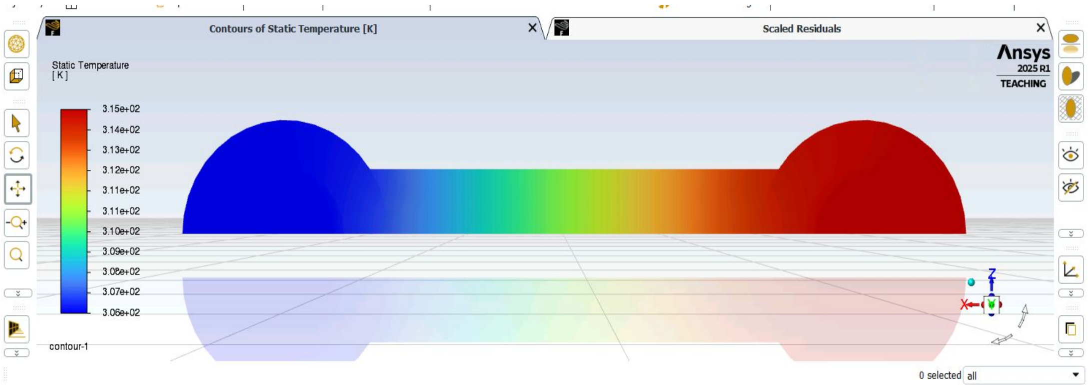


- 5.5” model

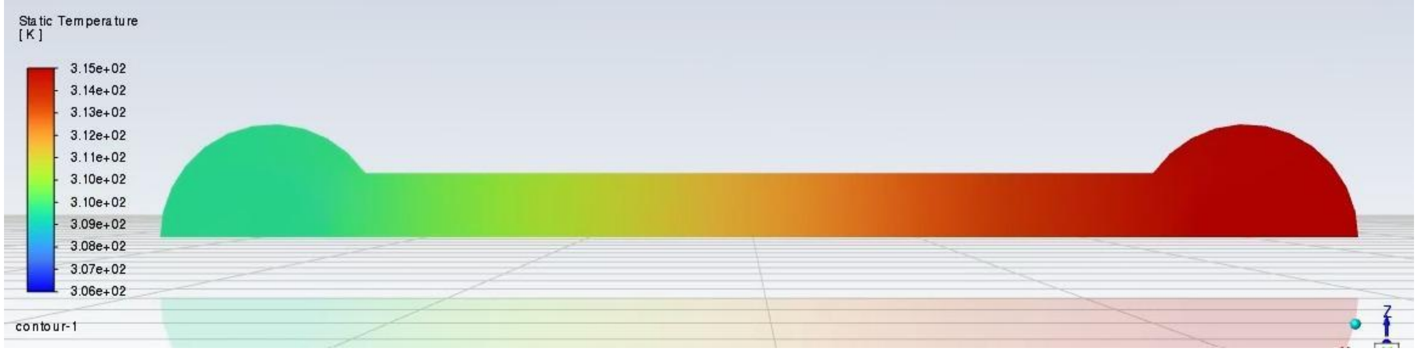


Ansys Fluent Results

- 6.5” model

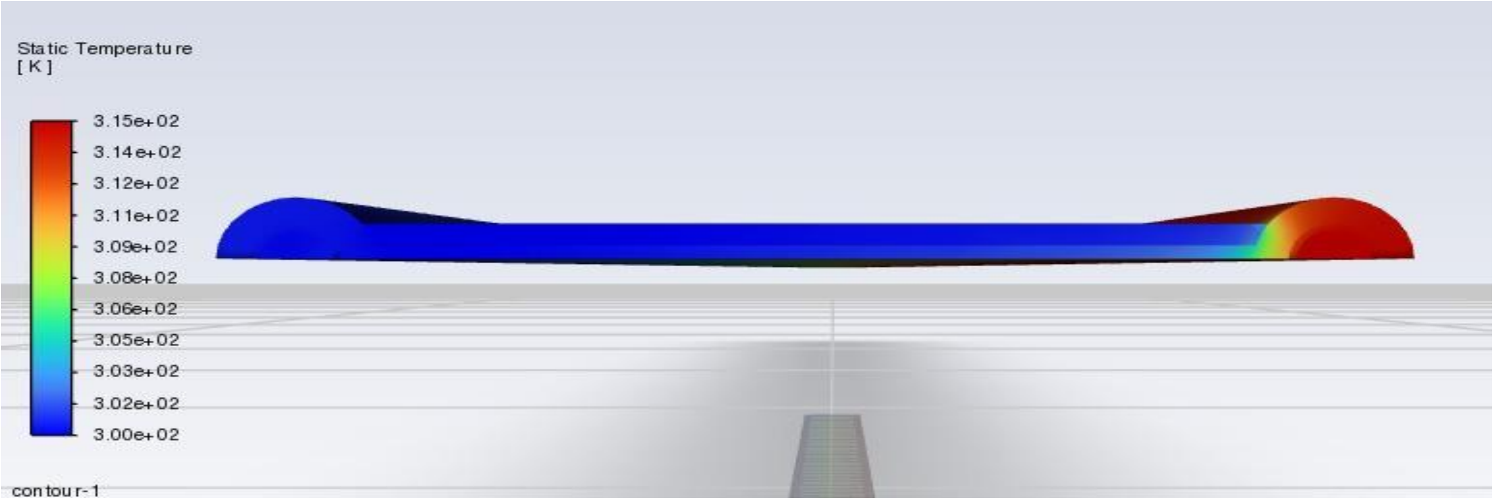


- 10” model

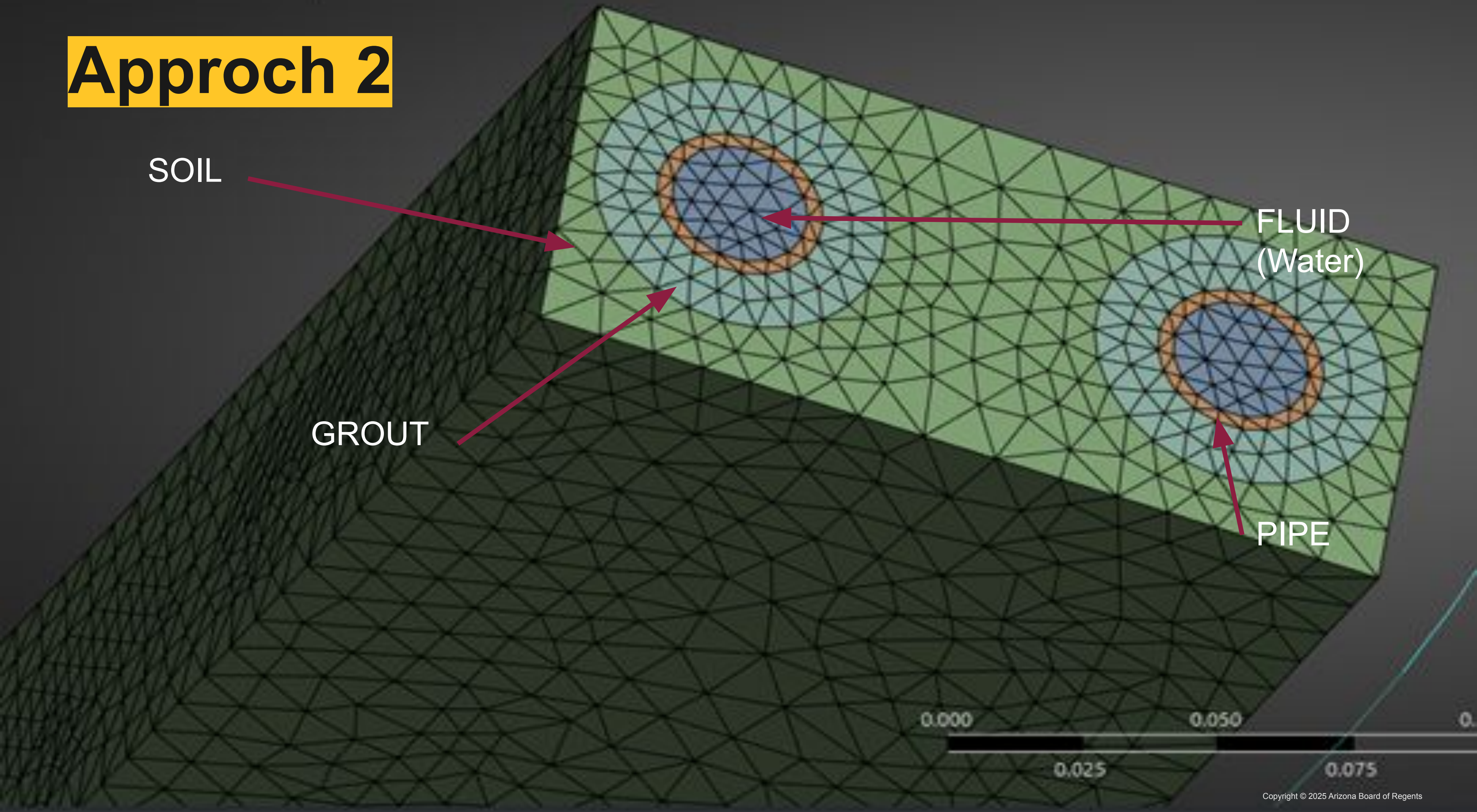


Ansys Fluent Results

- 15” model



Approch 2

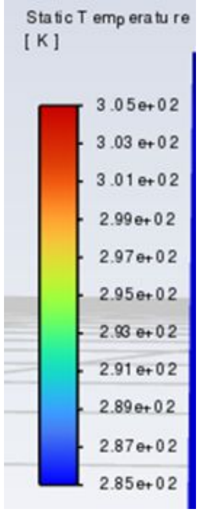


Ansys Fluent Model

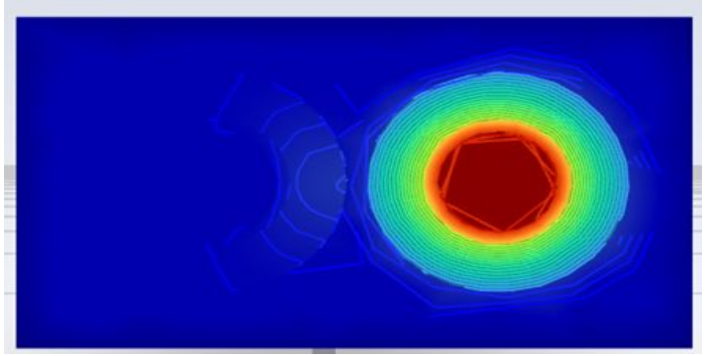
- Various geometries created by changing tube spacing between 2 and 15 inches
- Amount of short circuiting determined by change in outlet temperature of fluid with change in tube spacing
- Constant mass flow rate and constant pressure

Tube Spacing	Inlet Temperature [K]	Outlet Temperature [K]
2.5”	305	285.54
4”	305	285.25
6”	305	285.21
10”	305	285.20

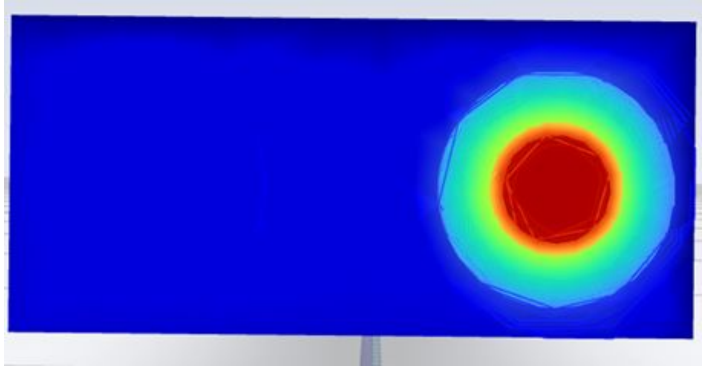
Ansys Fluent Results



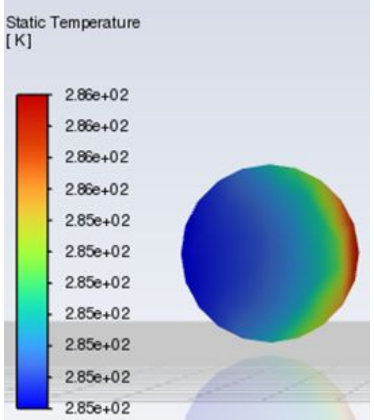
2.5” model



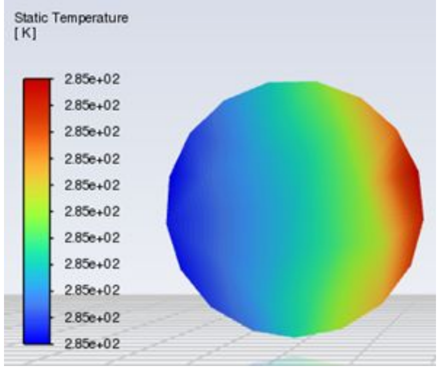
4” model



Outlet Temperature

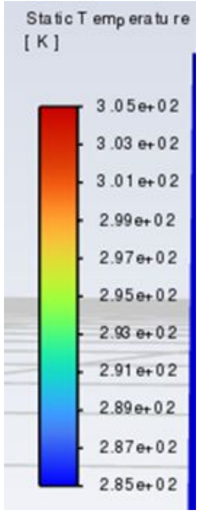


Min [K]	Max [K]
285.4214	285.5428

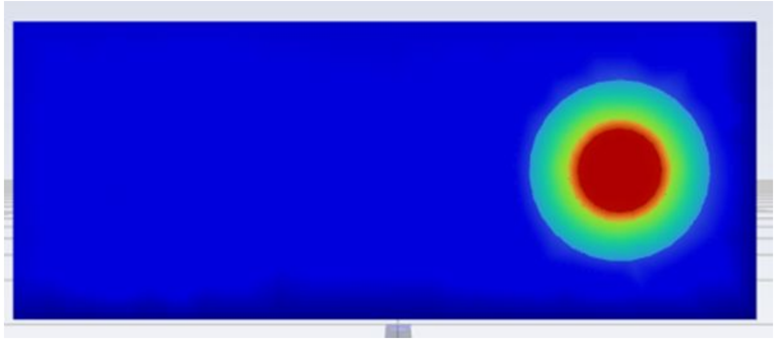


Min [K]	Max [K]
285.2509	285.2668

Ansys Fluent Results

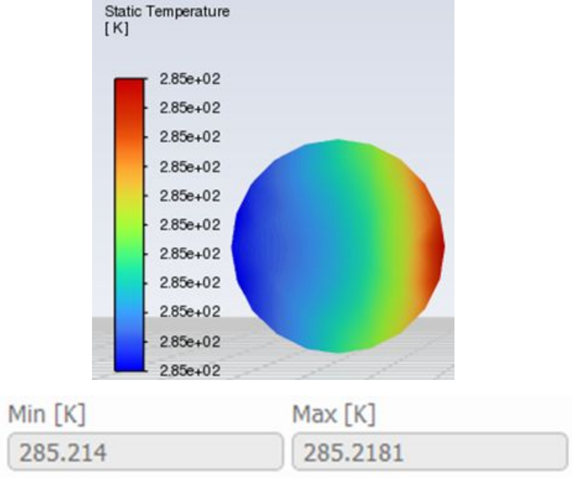


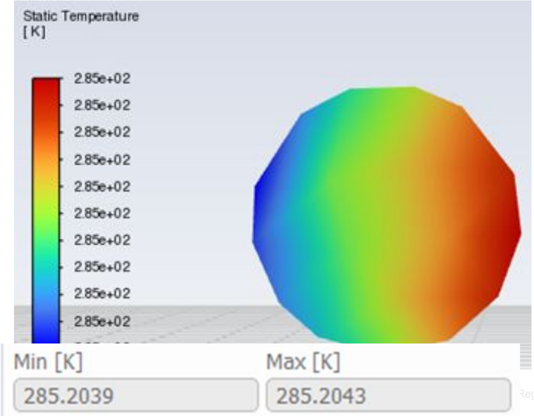
6” model



10” model

Outlet Temperature





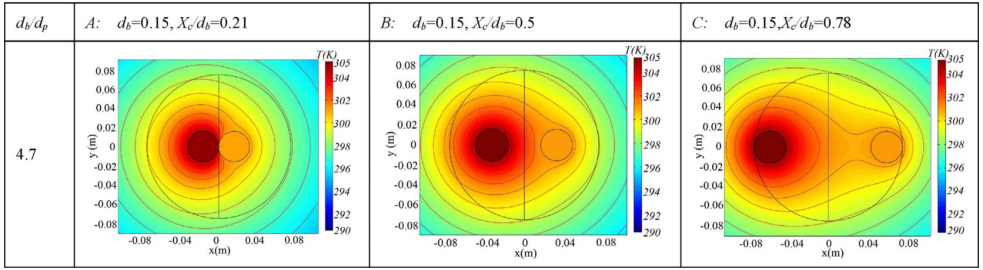
Results

- Outlet temperature at steady state was found to be largely independent of tube (shank) spacing in both modeling approaches, despite significant changes in the distance between tubes.

- **First Approach (Neglecting Soil and U-tube):**
  - Two tubes with varying shank spacing and grout between them.
  - Soil was neglected (assumed grout and soil have the same temperature).
  - Simulations showed nearly identical outlet temperatures for all tube spacings.
- **Second Approach (Including Soil and U-tube):**
  - Grout encased both tubes with soil filling the space in between, as per the illustrated geometry.
  - Simulations also showed the same outlet temperature for different shank spacings.

Comparison to Previous Results

- Previous work shows some amount of heat transfer between tubes in analysis with a large bore filled with grout.
- Exit temperature of fluid within contour plots is relatively constant between different shank spacing cases
- Results from two approaches provided similar results
  - thermally coupled by grout shows shank spacing influences exit temperature
  - thermally decoupled by grout shows less effect by shank spacing temperature
- Compared to previous results and papers, analysis conducted improves upon the fidelity of the models by including HDPE tubing, and considering both thermally coupled by grout and decoupled through soil by removing the borehole traditionally used in GHE



Results from prior work showing influence of shank spacing on thermal short circuiting [2]

Outcome of Project

- Most important outcome of the project is that an optimum spacing for single U-tube geothermal heat exchanger cannot be determined through steady state model but only through transient state analysis.
- From literature, grout plays important role in conducting heat away and reducing short circuiting between inlet and outlet of tubing
  - High conductivity grout will result in less thermal short circuiting
- Simplified model can help accelerate computing time to achieve similar result
  - Remove HDPE tubing
  - Mirroring geometry due to symmetry to reduce number of nodes / computing time
  - Use consistent meshing approaches / refinements in areas of interest

Outcome of Project

- Once steady state is reached, shank spacing acts only as a resistance to the rate of heat transfer but does not affect the final equilibrium outlet temperature.
- At steady state, the system reaches thermal equilibrium, and the outlet temperature depends mainly on the heat exchanger length, inlet conditions, and thermal properties—not the spacing.
- For steady-state analysis, optimizing tube spacing has minimal impact on final outlet temperature but could still affect transient (startup) performance or material costs.
- While shank spacing is important for mechanical design, pressure drop, and initial heat transfer rates, for long-term/steady-state operation, temperature outcome is dominated by geometry length and boundary conditions.

References

- [1]G. Tom and A. Mwesigye, “COLLECTION AND ANALYSIS OF SOIL THERMAL PROPERTY DATA UNDER MINNESOTA’S LOCAL CONDITIONS,” *University Digital Conservancy Home*, 08-Aug-2021.

- [2]Y. Li, J. Mao, S. Geng, X. Han, and H. Zhang, “Evaluation of thermal short-circuiting and influence on thermal response test for borehole heat exchanger,” *Geothermics*, vol. 50, pp. 136–147, Oct. 2014.

- [3]“High density polyethylene,” *High Density Polyethylene | Centennial Plastics, Inc*. [Online]. Available: https://centennialplastics.com/products/hdpe/.

- [4]Christopher Vella, Simon Paul Borg * and Daniel Micallef,”The Effect of Shank-Space on the Thermal Performance of Shallow Vertical U-Tube Ground Heat Exchangers”,29-Jan-2020