# A numerical study on ground heat exchangers and the effect of their design on the performance of geothermal systems

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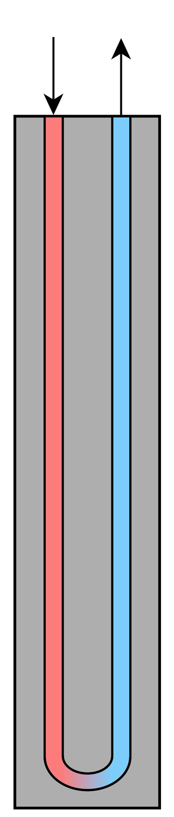
## Highlights

This study uses OpenFOAM to model the conjugate heat transfer that occurs in and around a ground heat exchanger. Some key challenges to modelling are:

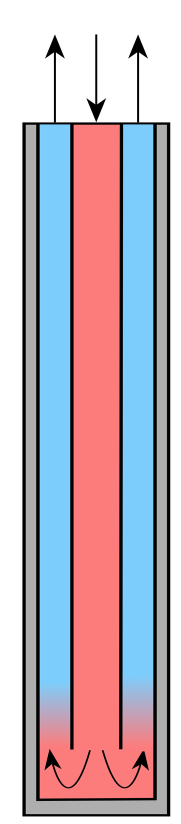
- A domain containing a long, slender borehole and a large volume of soil, resulting in high aspect ratio cells
- Heat transfer that is mainly in the radial direction but with axial heat transfer and convection that cannot be ignored
- The need to understand not only long-term performance (over years, decades) but also transient behaviour over short time scales, which can have a significant impact on performance

Borehole heat exchangers are the key component that enables heat transfer with the ground in many geothermal systems, such as ground source heat pumps or geothermal storage. These heat exchangers are installed inside a drilled well and consist of tubing, to allow for fluid flow, surrounded by grout, which acts to seal the borehole and enhance heat transfer to the ground.

The most common borehole designs are the u-tube and coaxial, shown in Figure 1. The u-tube design contains of a u-shaped tube for fluid flow, while the coaxial involves a tube-in-tube design. The boreholes have typical diameters of 15 cm and depths ranging from 20 to 200 m.



(a) U-tube borehole heat exchanger



(b) Coaxial borehole heat exchanger

Figure 1: Borehole heat exchanger designs, consisting of tubing placed in a well in the ground, surrounded by grout

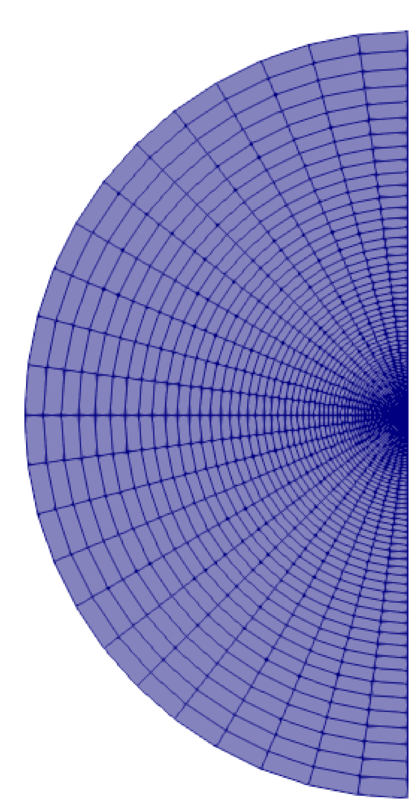
CFD was chosen to model these heat exchangers because while there are simplified analytical and semi-analytical models that capture some of their behaviour, no analytical model thoroughly represents the complex, conjugate heat transfer in these systems over all time scales. The objective of this modelling is to use high-fidelity CFD to represent this transient, coupled behaviour. This enables the study of borehole performance under intermittent operating conditions as well as the interaction of multiple boreholes in a system. This poster discusses the experimental validation of these models, which are currently being used to conduct these studies.

## Numerical Modelling

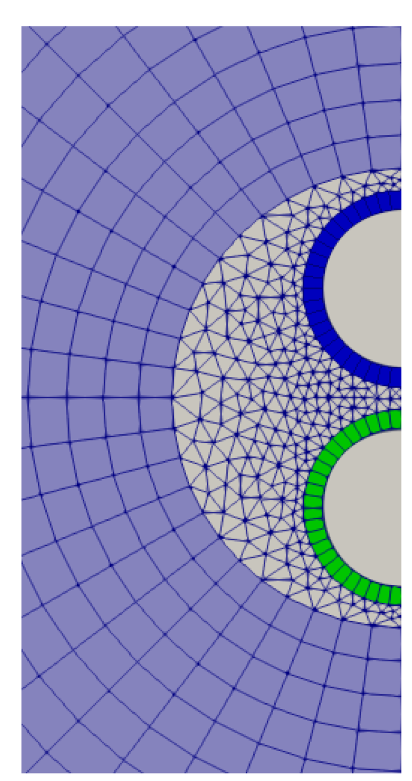
These models were resolved using a solver developed based on chtMultiRegionFoam, which allowed for coupled heat transfer between multiple regions: the heat transfer fluid, tubing, grout, and the ground.

The u-tube and coaxial meshes, which make use of symmetry, are depicted in Figure 2, below.

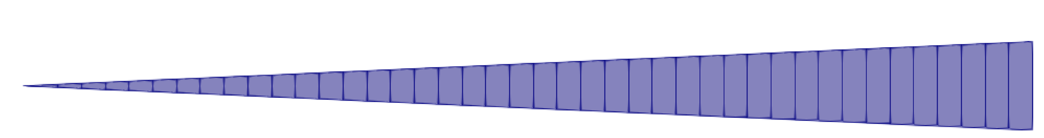
As the fluid flow is simple pipe flow, it was represented as one-dimensional, with convective heat transfer accounted for using the Gnielinski correlations for round and annular ducts [1, 2].



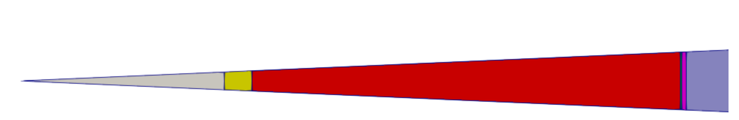
(a) Radially expanding soil domain



(b) U-tube borehole at the centre of the soil



(c) Radially expanding soil domain



(d) Coaxial borehole at the centre of the soil

Figure 2: Meshes used to model boreholes, with the u-tube domain using 180° symmetry, and an axisymmetric geometry in the coaxial design

To accommodate a 1D approach, a semi-circular mesh was developed for the fluid in the u-tube model, Figure 3.

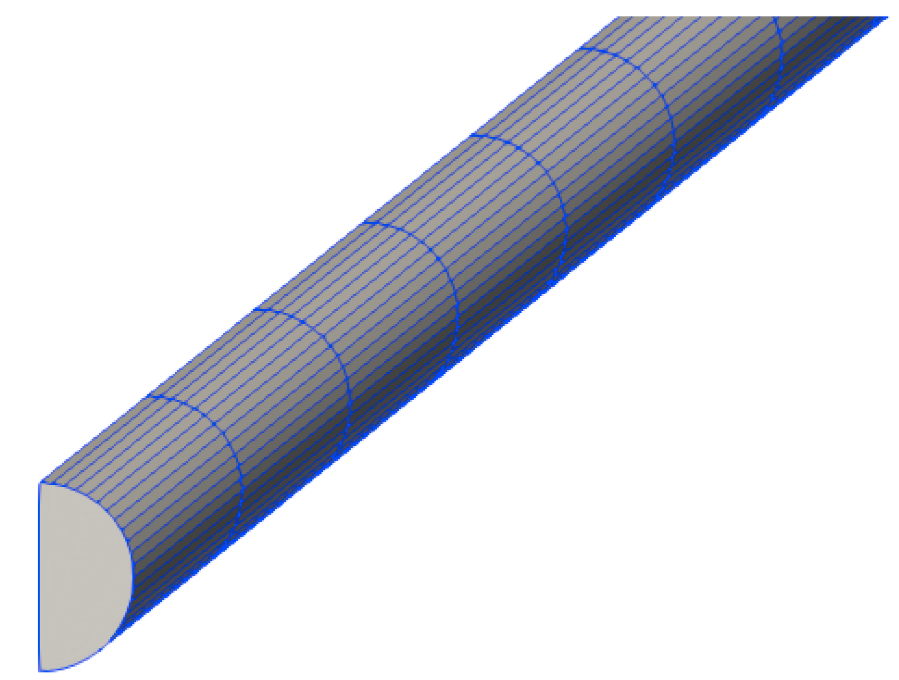


Figure 3: 1D fluid mesh, with single cells advancing in the z-direction and multiple faces on curved surface

The governing equation of the fluid was defined such that the convection heat transfer was contained in a source term:

```
fvScalarMatrix TEqn
(
    fvm::ddt(rho*cp,T) + fvm::div(phi,T)
        - fvm::Su(source,T)
);
```

where the source term is:

$$source = \frac{hA_{surf}}{V}\left(\overline{T}_{wall} - T_{fluid}\right)$$

where $A_{surf}$ is the pipe surface area and $\overline{T}_{wall}$ is the average temperature of the wall at a given z location. The heat transfer within the solid domains was pure, isotropic conduction. Coupling between solids was achieved using compressible::turbulentTemperatureCoupledBaffleMixed, and fluid-solid coupling was handled using a custom boundary where temperatures were equal and the heat flux was equal to the convective heat transfer.

## Experimental Validation

The u-tube and coaxial models were compared to in-situ results from thermal response tests (TRTs). These tests involve injecting a fixed amount of heat into the borehole, which is achieved by using a heater and a pump outside the borehole to supply fluid at a constant flow rate. This scenario was replicated by setting the inlet temperature of the fluid entering the borehole equal to fixed temperature increase relative to the outlet temperature:

$$T_{inlet} = T_{outlet} + \frac{\dot{Q}}{\dot{m}c_p}$$

This inlet condition was achieved using groovyBC.

The results of the experimental validation are shown in Figures 4 and 5, below.

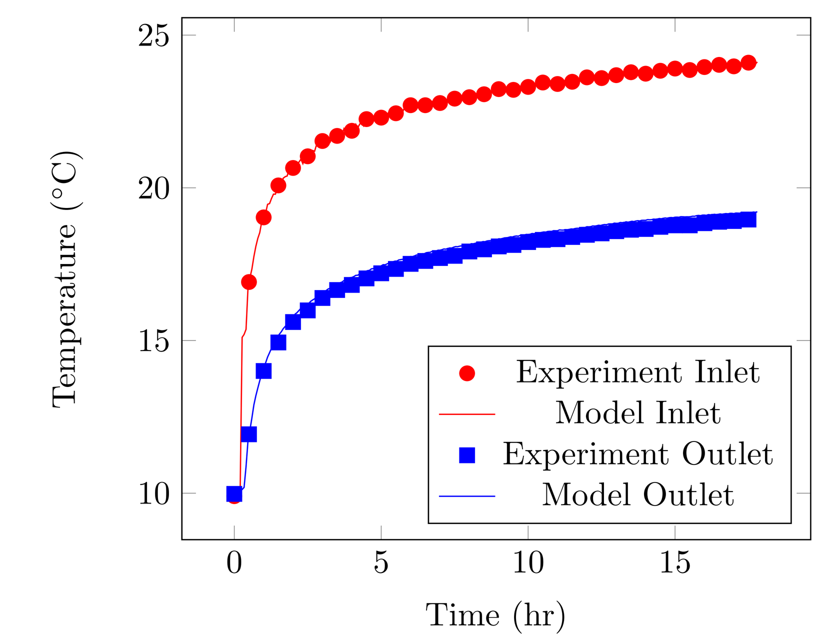



Figure 4: Comparison of u-tube borehole model with experimental TRT results from GeoSource Energy

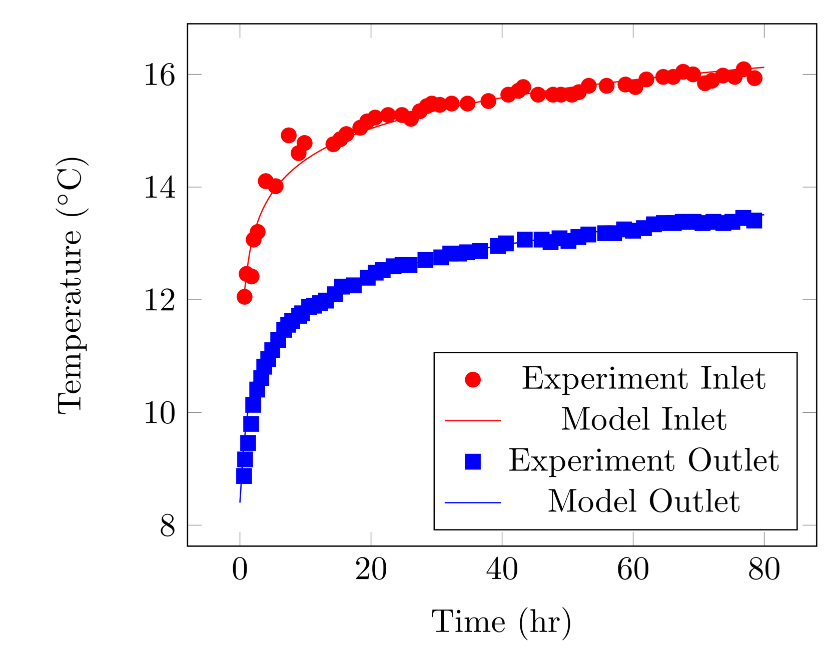



Figure 5: Comparison of coaxial borehole model with experimental TRT results from Beier *et al.* [3]

These results show that both the inlet and outlet temperatures of the boreholes agree well with the experimental results. Since the experimental inlet temperatures were not used directly in the simulations, the fluctuations present in the experimental values is not reflected in the simulation results. The simulations, however, produced smooth curves that matched very closely with the trends of the TRT. At the end of each simulation, the outlet temperature error was within 1%.

## References

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