GLHEPRO Inputs
Borehole design

Part 1

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Outline

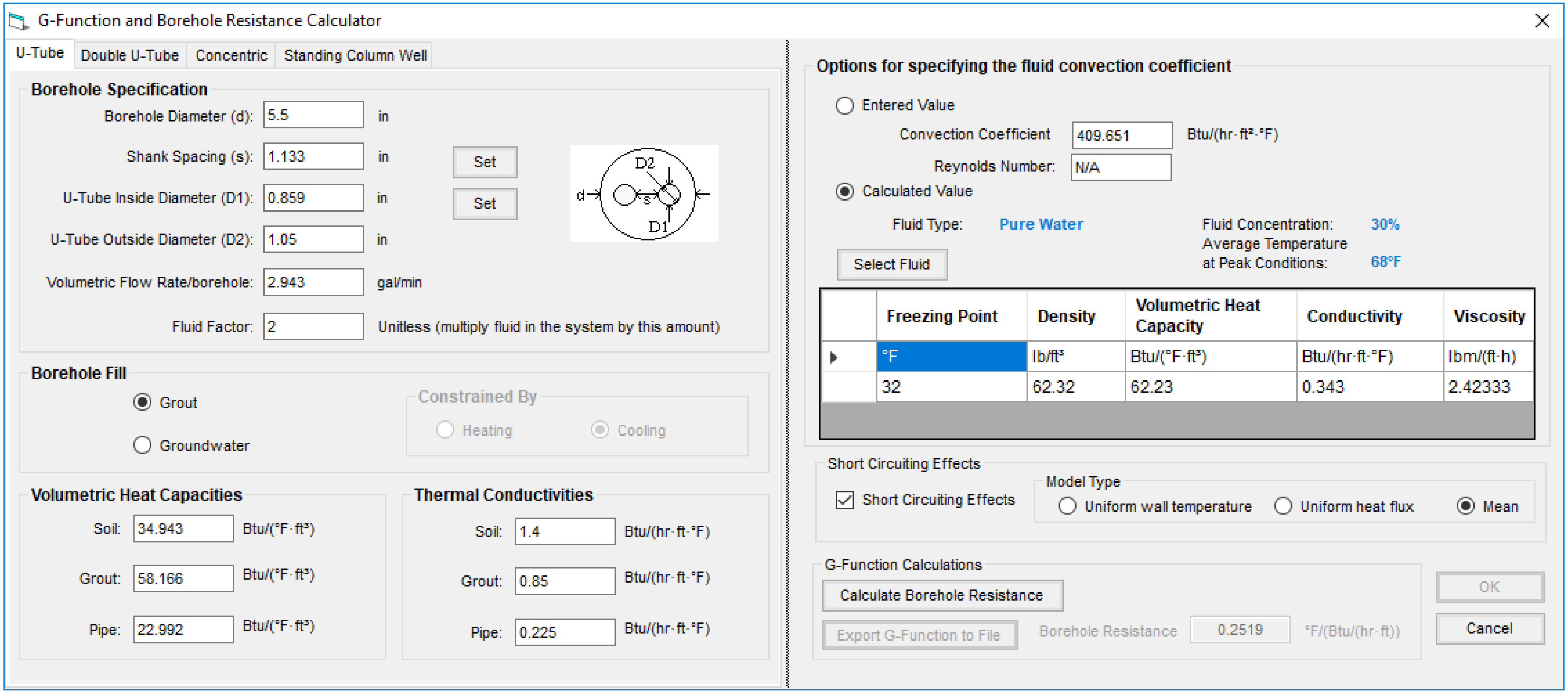
- Introduce user to specification (and modeling) of the borehole design:
    - Borehole geometry
    - Flow rate & fluid factor
    - Borehole filling: grout & groundwater
    - Convection
    - Short-Circuiting
    - Geometries other than single U-tube

Goals

- The main goals of this lecture are to introduce:
  - Specification of the borehole design.
  - Modeling of the borehole design.
  - Provide references for the modeling.
- This lecture is not intended to:
  - Explain the theory or modeling in detail.
  - Give complete guidance on how to make a good borehole design.

Goals

- Or, what to do with this:



G-Function and Borehole Resistance Calculator

Borehole Specification

Borehole Diameter (d): 5.5 in

Shank Spacing (s): 1.133 in

U-Tube Inside Diameter (D1): 0.859 in

U-Tube Outside Diameter (D2): 1.05 in

Volumetric Flow Rate/borehole: 2.943 gal/min

Fluid Factor: 2 Unitless (multiply fluid in the system by this amount)

Borehole Fill

● Grout

○ Groundwater

Constrained By: ○ Heating ● Cooling

Volumetric Heat Capacities

Soil: 34.943 Btu/(°F·ft³)

Grout: 58.166 Btu/(°F·ft³)

Pipe: 22.992 Btu/(°F·ft³)

Thermal Conductivities

Soil: 1.4 Btu/(hr·ft·°F)

Grout: 0.85 Btu/(hr·ft·°F)

Pipe: 0.225 Btu/(hr·ft·°F)

Options for specifying the fluid convection coefficient

○ Entered Value

Convection Coefficient 409.651 Btu/(hr·ft²·°F)

Reynolds Number: N/A

● Calculated Value

Fluid Type: Pure Water

Fluid Concentration: 30%

Average Temperature at Peak Conditions: 68°F

Freezing Point	Density	Volumetric Heat Capacity	Conductivity	Viscosity
°F	lb/ft³	Btu/(°F·ft³)	Btu/(hr·ft·°F)	lbm/(ft·h)
32	62.32	62.23	0.343	2.42333

Short Circuiting Effects

☑ Short Circuiting Effects

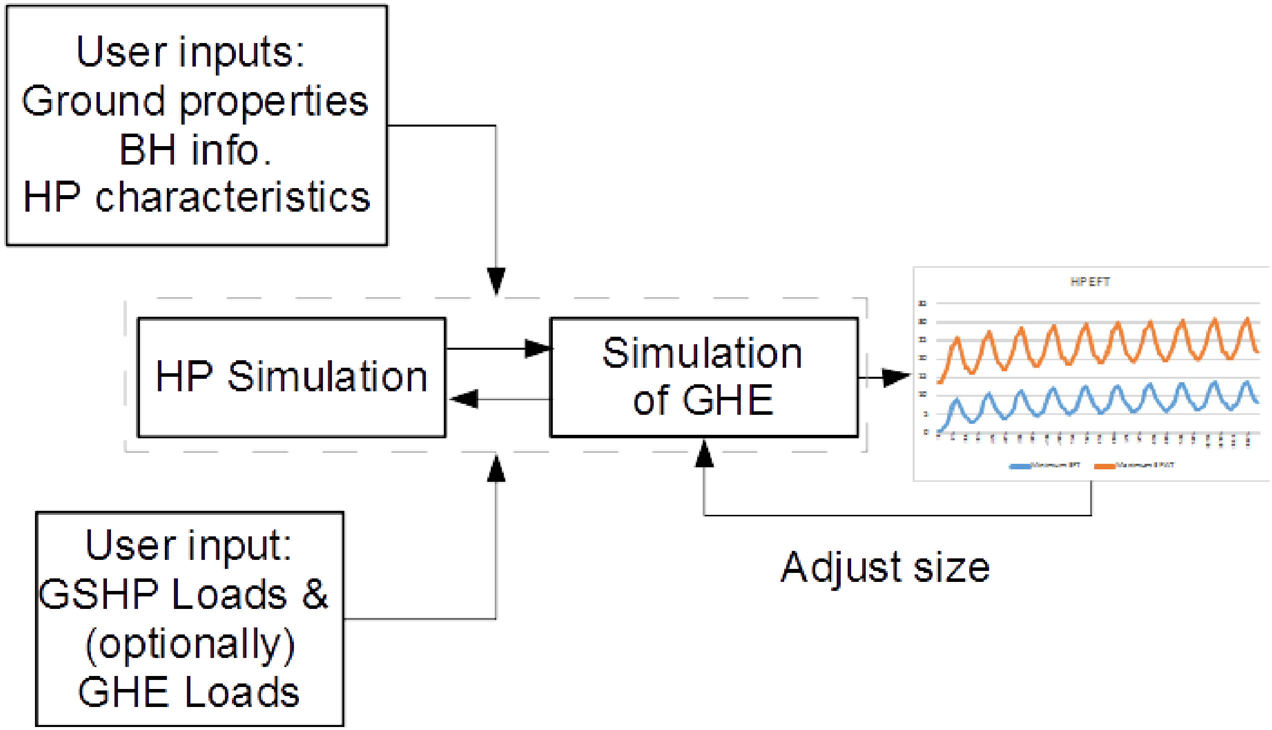
Model Type: ○ Uniform wall temperature ○ Uniform heat flux ● Mean

G-Function Calculations

Borehole Resistance 0.2519 °F/(Btu/(hr·ft))

Purpose of the Borehole Model

- How does the design of the borehole affect the heat pump entering fluid temperatures?



User inputs:
Ground properties
BH info.
HP characteristics

HP Simulation

Simulation of GHE

User input:
GSHP Loads &
(optionally)
GHE Loads

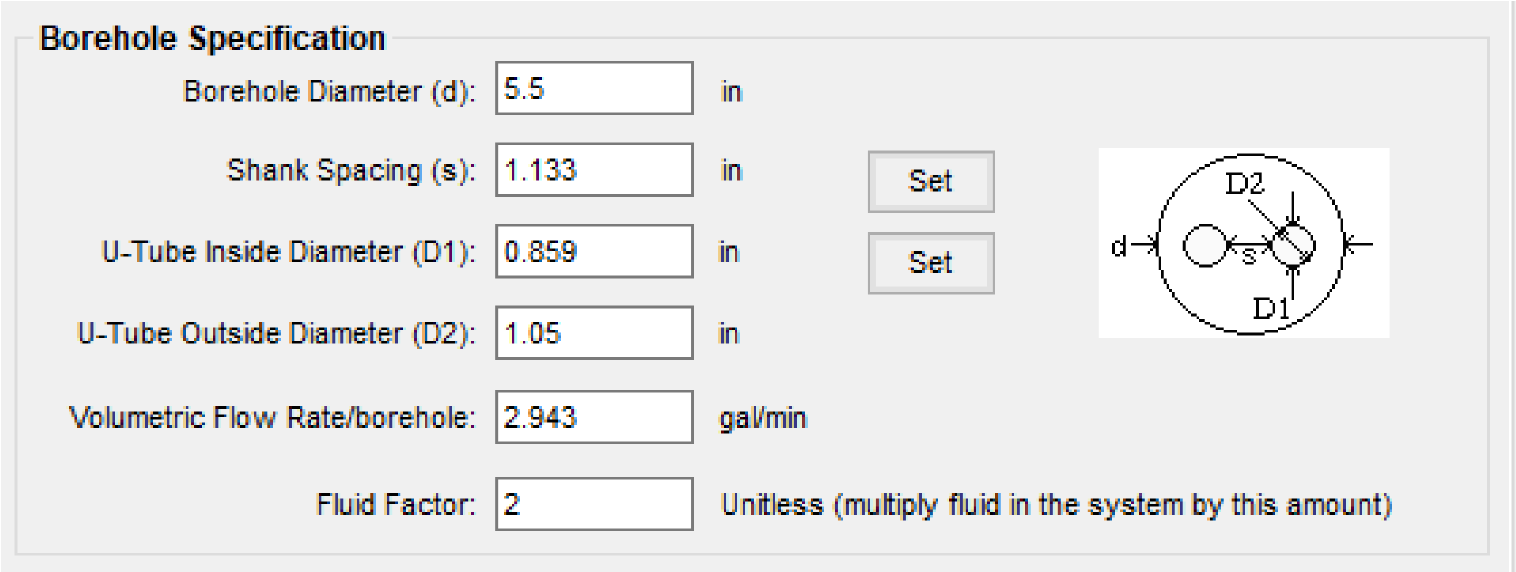
Adjust size

Limitations of the borehole model

- It computes a borehole resistance and short time step response corresponding to a single fluid temperature.
- For design purposes, the temperature should be near the design condition, for heating or cooling – whichever situation constrains the design.

Borehole specification (geometry)

- Tube diameter and position can be set with the “Set” buttons.
- Volume flow rate determined automatically based on system flow rate and number of boreholes.
- “B spacing” recommended for uncontrolled placement of U-tube



Borehole Specification

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Shank Spacing (s):	1.133	in
U-Tube Inside Diameter (D1):	0.859	in
U-Tube Outside Diameter (D2):	1.05	in
Volumetric Flow Rate/borehole:	2.943	gal/min
Fluid Factor:	2	Unitless (multiply fluid in the system by this amount)

Important caveat!

- A critical but often overlooked aspect of the design is the hydraulic design:
  - Managing the overall pressure loss in the ground heat exchanger.
  - Many a system design has been ruined by ignoring this.
- Design guidance from Kirk Mescher (ASHRAE 2011):
  - No more than 25 feet or 7.6 meters of head loss in GHE.
  - No more than 50 feet or 15.2 meters of head loss in system, including GHE, heat pump(s) and other components.

Minimum flows

- Early guidance, still repeated:
  - Flow should be turbulent. (Bare minimum Re > 2300)
  - This is workable for cooling-dominated systems.
  - Problematic for heating-dominated systems using antifreeze mixtures.
- See Gehlin and Spitler (2015)

Fluid factor

- The fluid factor accounts for the thermal mass of the fluid outside the ground heat exchanger.

$$Fluid\ factor = \frac{Total\ mass\ of\ fluid\ in\ system}{Mass\ of\ fluid\ in\ boreholes}$$

  - See Young (2004)
  - More important for designs dominated by peak loads.

GLHEPRO Inputs Borehole design

Part 2

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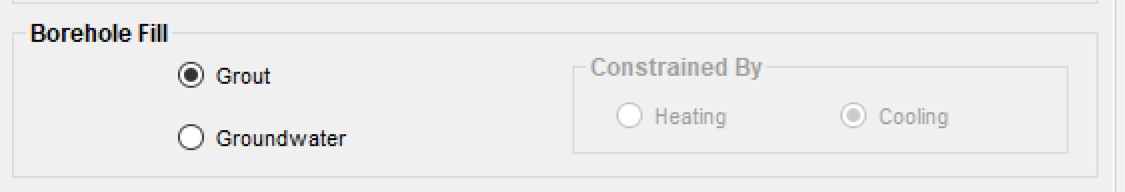
Borehole fill

- Most North American boreholes are backfilled with grout.
- In Scandinavia, where there is hard rock, it is common to use groundwater-filled boreholes.
- GLHEPRO can handle either situation.
- Groundwater-filled boreholes limited to single U-tube.



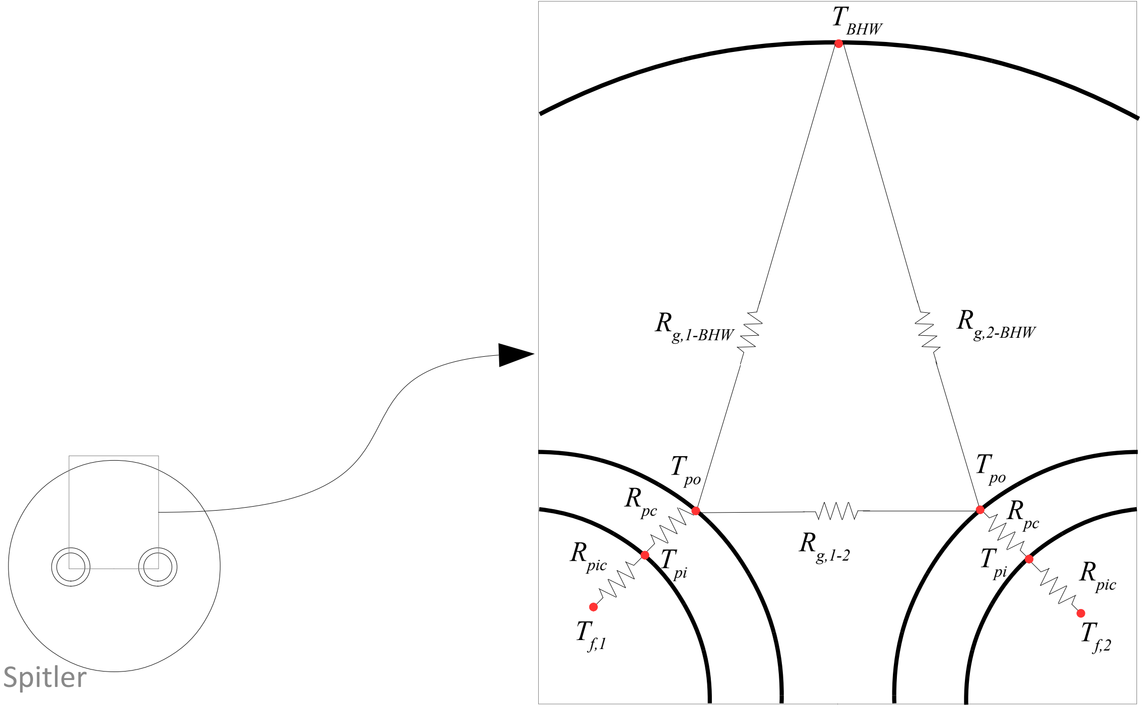
Borehole Fill

● Grout

○ Groundwater

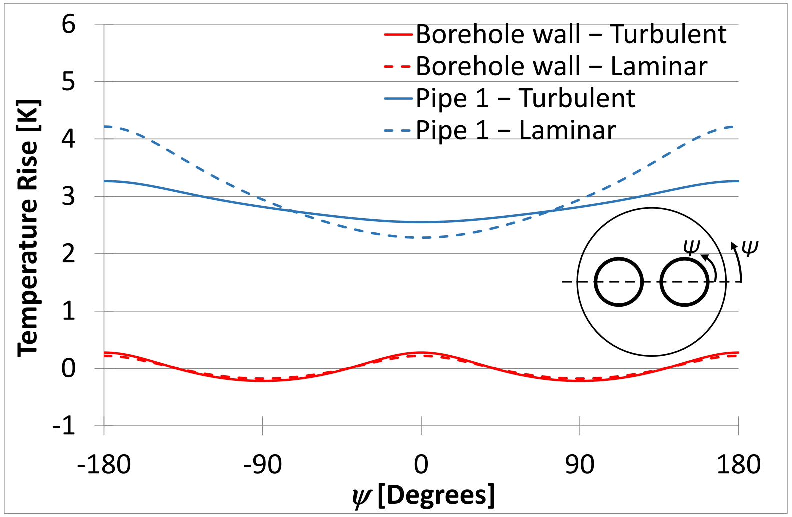
Modeling of grouted boreholes

- Resistance computed with multipole method.
  - Developed by Johan Claesson and students (Claesson and Bennet 1987; Claesson and Hellström 2011)
  - We use 10th order multipoles.
  - Newer, simpler (closed-form) expressions are available. (Claesson and Javed 2018, 2019; Javed and Spitler 2016, 2017)



Modeling of grouted boreholes

- I highly recommend:
  - Javed and Spitler (2016) as background for researchers.
  - And Javed and Spitler (2016, 2017) for anyone wanting to understand accuracy and arcane matters such as why the ground thermal properties affect the borehole thermal resistance.

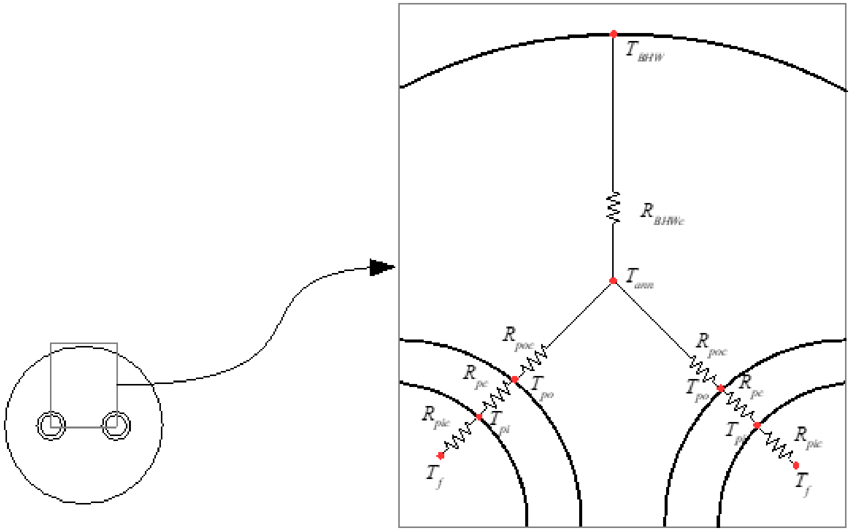


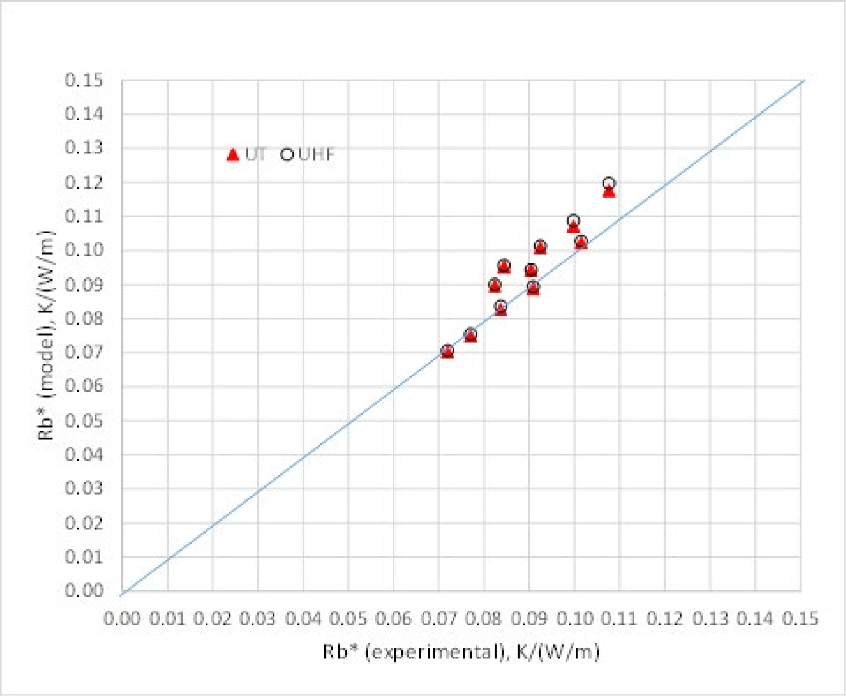
Source: Javed and Spitler (2017)

Modeling of groundwater-filled boreholes

- Natural convection in borehole outside of the U-tube.
- One possibility is to modify the grout properties to approximate the expected borehole resistance.
- Spitler, et al. (2017) developed convection correlations for the outside of the tube wall and the borehole wall.
- Borehole resistance of groundwater-filled boreholes is highly changeable due to the buoyancy-driven heat transfer.
- Important to get correct design conditions!

Spitler, Javed and Ramstad (2017)





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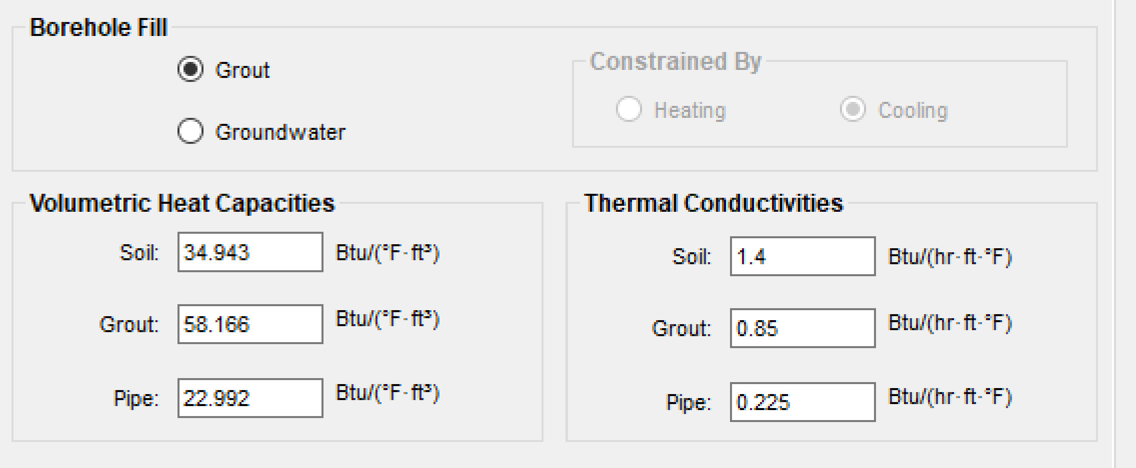
- Mostly a matter of getting geometry and thermal properties correct.



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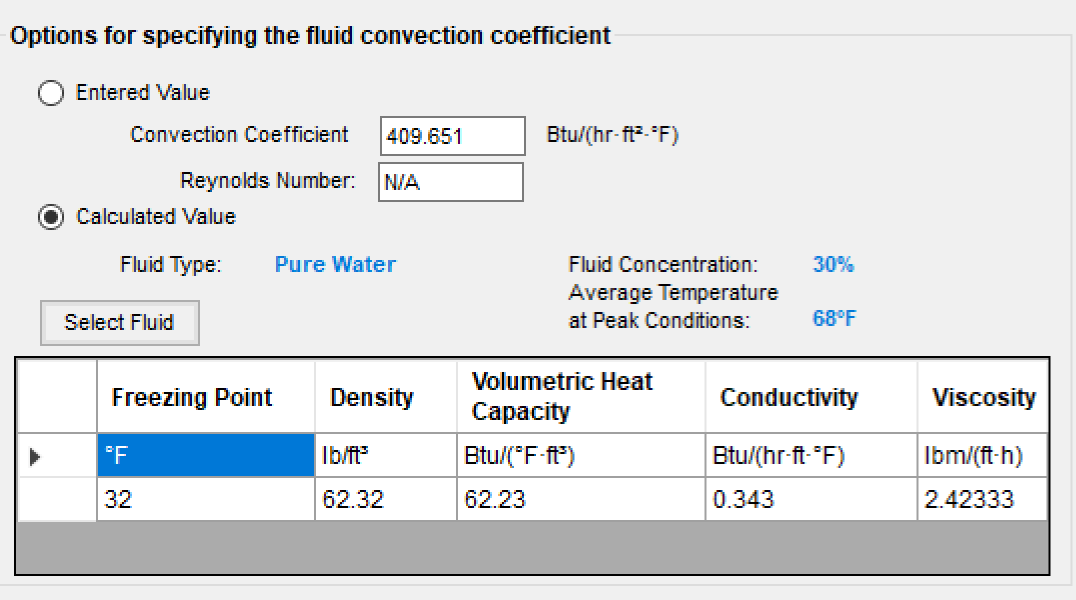
- Reason for inputting volumetric specific heats:
  - When borehole thermal resistance is calculated, we also calculate the short-time-step g-function.
  - See Xu and Spitler (2006)

Convection Coefficient

- Computed by the program.
- (Can also be specified directly.)
- Changes when number of boreholes change, so be sure to recalculate the borehole thermal resistance.



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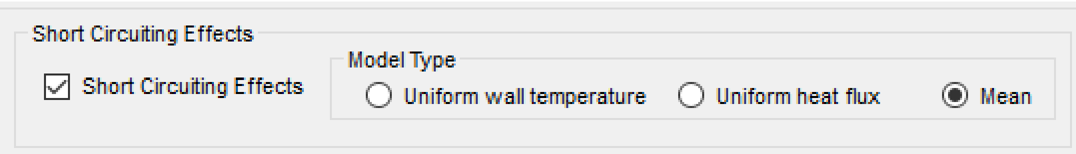
Short-circuiting

- I address this in "Ground Heat Exchangers - Introduction to Modeling - Part 2"
- Both of Hellström's (1991) expressions are used here.
- Mean value of the two expressions can be used.



Short Circuiting Effects

☑ Short Circuiting Effects

Model Type

○ Uniform wall temperature ○ Uniform heat flux ● Mean

General comments

- Decreasing the borehole thermal resistance will decrease the required size of the ground heat exchanger.
- Possible measures to decrease borehole thermal resistance:
    - Thermally-enhanced grout.
    - Moving pipes closer to the borehole wall.
    - Smaller borehole diameter.
    - Thermally-enhanced pipe.
    - Thermally-enhanced fluid.

General comments

- The ability to decrease the GHE size depends highly on ground thermal properties.
  - Higher conductivity rock gives greater potential to reduce GHE size.
- The ability to implement the measures often involves a trade-off between:
  - Installation time and cost.
  - Thermal performance.
- There are many schemes that will actually reduce the borehole thermal resistance, but are not, alas, economically feasible.

General Comments

- Some schemes (e.g. double U-tubes with spacers) are more feasible when there is:
  - Hard rock, or
  - Limited ground surface area, or
  - Drilling is more expensive.
- There are some schemes that are extremely difficult to install, e.g. “the spider”.
- Finally, please don’t forget: the purpose of the grout is to protect the groundwater from infiltration of surface pollutants.

GLHEPRO Inputs Borehole design

Part 3 – Live demo

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Live demo here

GLHEPRO Inputs Borehole design

Part 4 – Live demo

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Live demo here

References

- Software
  - GLHEPRO: https://hvac.okstate.edu/glhepro/overview
- References
  - GLHEPRO Manual*

* available at https://hvac.okstate.edu

References

ASHRAE 2011. Ground Source Heat Pump Systems: Putting the Earth to Work for You. ASHRAE Webcast DVD. Atlanta, ASHRAE.

Claesson, J. and J. Bennet 1987. Multipole Method to Compute the Conductive Heat Flows to and between pipes in a cylinder. Dept. of Building Technology and Mathematical Physics.

Claesson, J. and G. Hellström. 2011. *Multipole method to calculate borehole thermal resistances in a borehole heat exchanger.* HVAC&R Research 17(6): 895-911.

Claesson, J. and S. Javed. 2018. *Explicit Multipole Formulas for Calculating Thermal Resistance of Single U-Tube Ground Heat Exchangers*. Energies 11(1): 214.*

Claesson, J. and S. Javed. 2019. *Explicit multipole formulas and thermal network models for calculating thermal resistances of double U-pipe borehole heat exchangers*. Science and Technology for the Built Environment 25(8): 980-992.

* Open access

References

Gehlin, S. E. A. and J. D. Spitler 2015. Effects of ground heat exchanger design flow velocities on system performance of ground source heat pump systems in cold climates. ASHRAE Winter Conference. 2014.*

Hellström, G. 1991. *Ground Heat Storage – Thermal Analyses of Duct Storage Systems - Theory* PhD Doctoral Thesis, University of Lund.

Javed, S. and J. Spitler. 2017. *Accuracy of borehole thermal resistance calculation methods for grouted single U-tube ground heat exchangers*. Applied Energy 187: 790-806.

Javed, S. and J. D. Spitler 2016. Calculation of borehole thermal resistance in Advances in Ground-Source Heat Pump Systems. Amsterdam, Woodhead Publishing: 63-95.

Xu, X. and J. D. Spitler. 2006. *Modelling of Vertical Ground Loop Heat Exchangers with Variable Convective Resistance and Thermal Mass of the Fluid*. 10th International Conference on Thermal Energy Storage - Ecostock 2006, Pomona, NJ.*

Young, T. R. 2004. *Development, Verification, and Design Analysis of the Borehole Fluid Thermal Mass Model for Approximating Short Term Borehole Thermal Response*. MS, Oklahoma State University.*

* available at https://hvac.okstate.edu