

# In-Situ Test Interpretations for Coaxial Ground Heat Exchangers

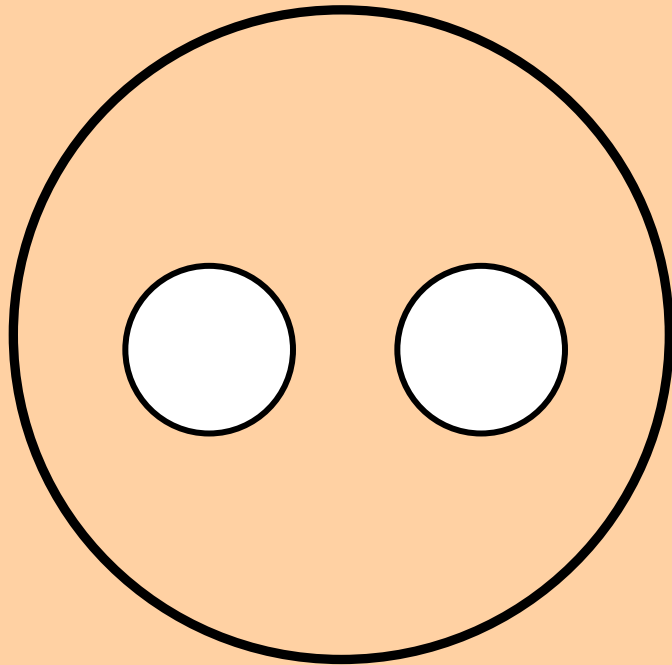
Richard A. Beier

Mechanical Engineering Technology Department  
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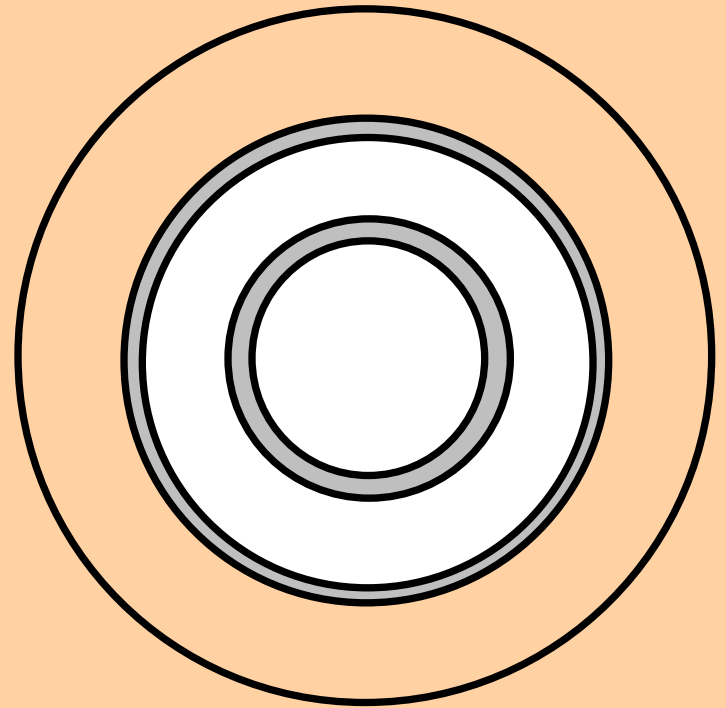
Participant in the  
OG&E Ground Source Heat Exchanger Study

# Ground Heat Exchangers

**U-tube**

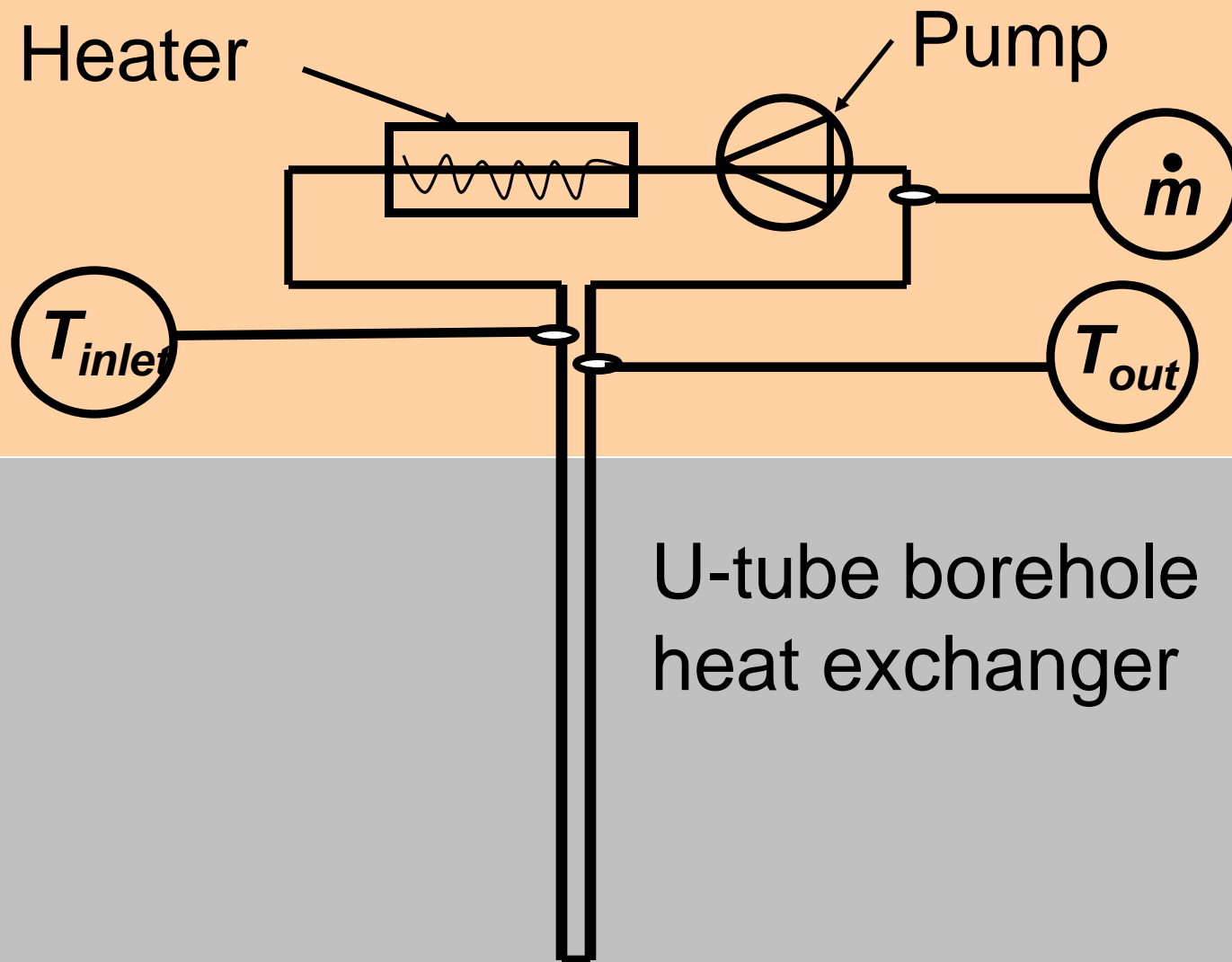


**Coaxial**

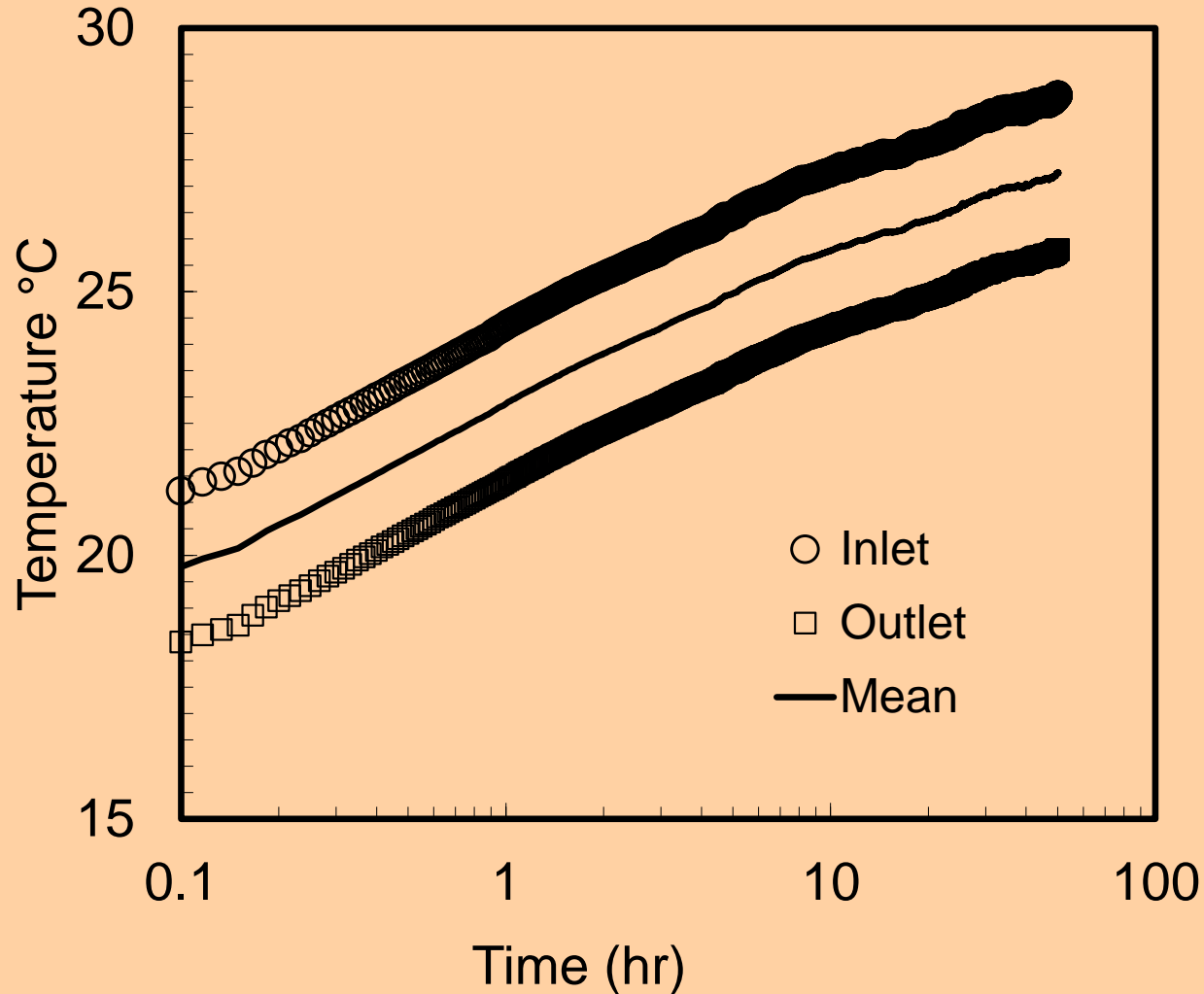


# In-Situ Thermal Response Test

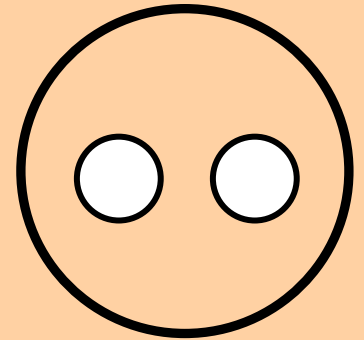
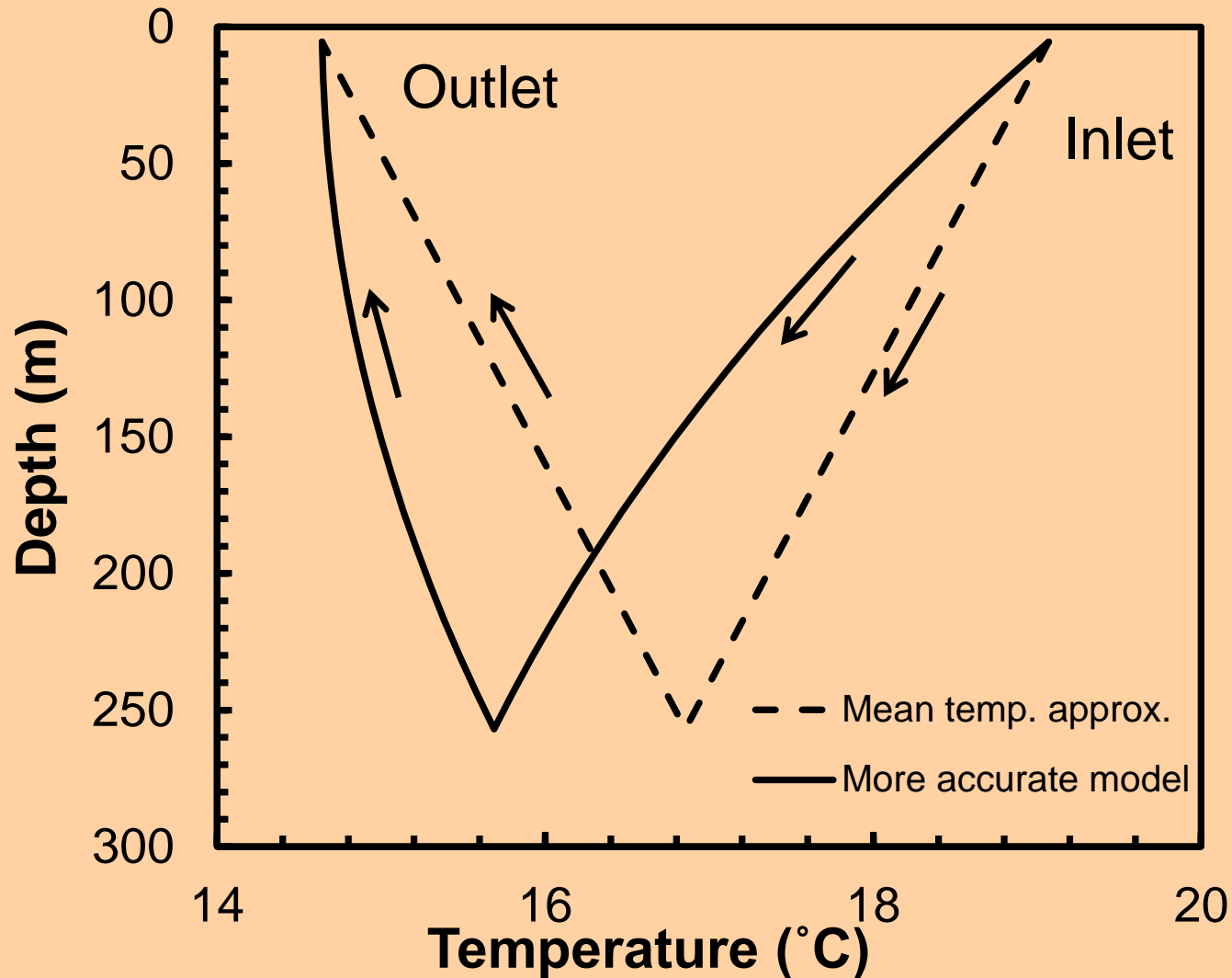
- U-tube boreholes
- Coaxial boreholes
- Vertical temperature profiles
- Estimate soil thermal conductivity
- Estimate of borehole resistance



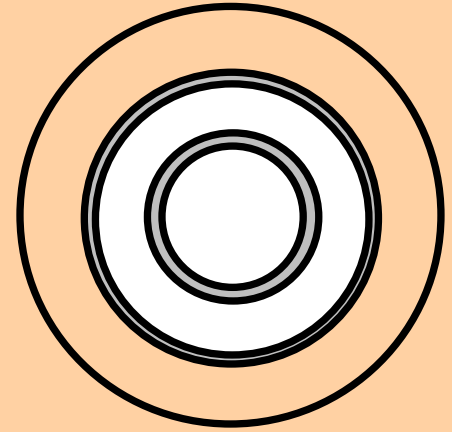
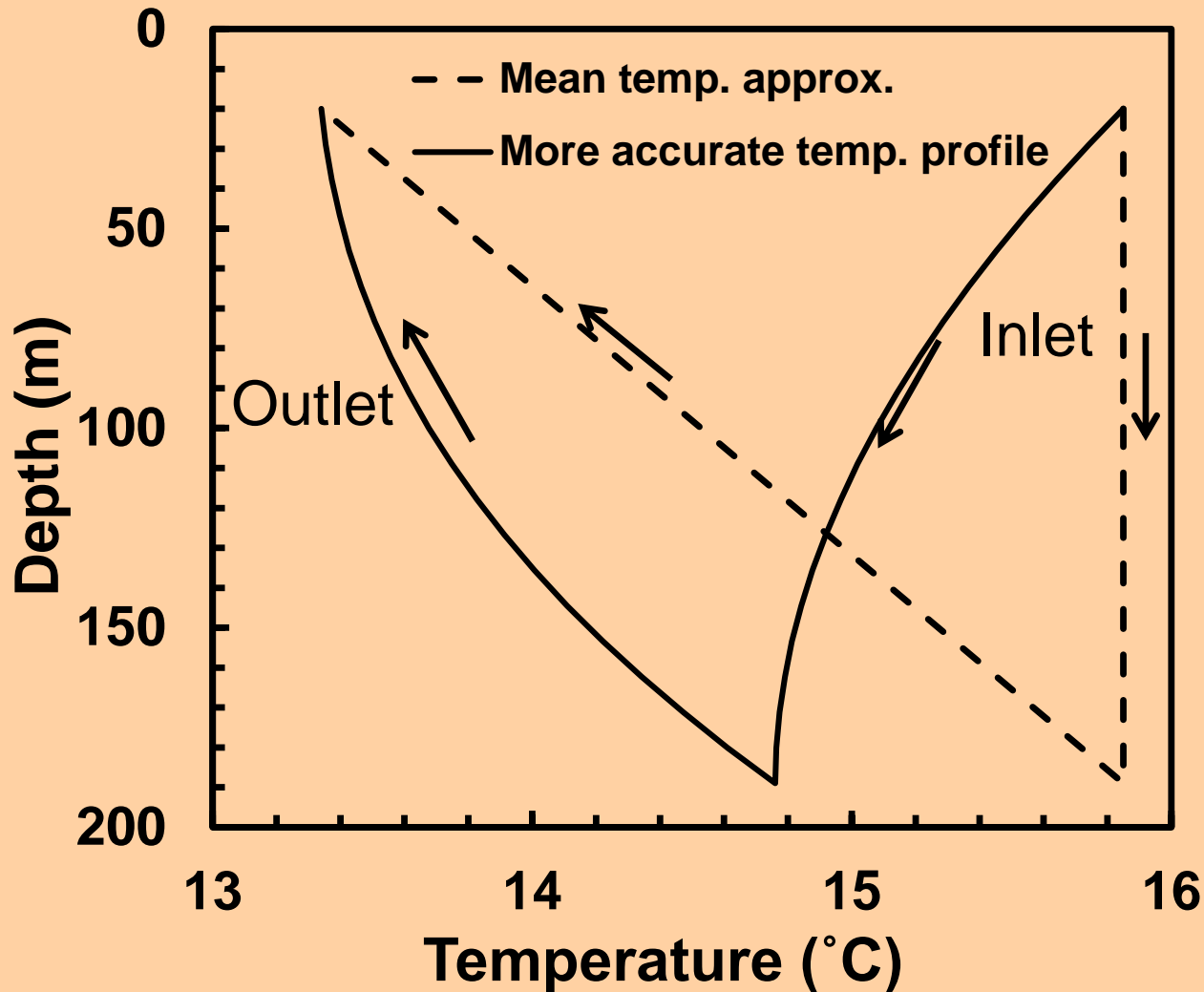
# Mean Temperature Approximation



# Vertical Temperature Profiles U-tube Heat Exchanger

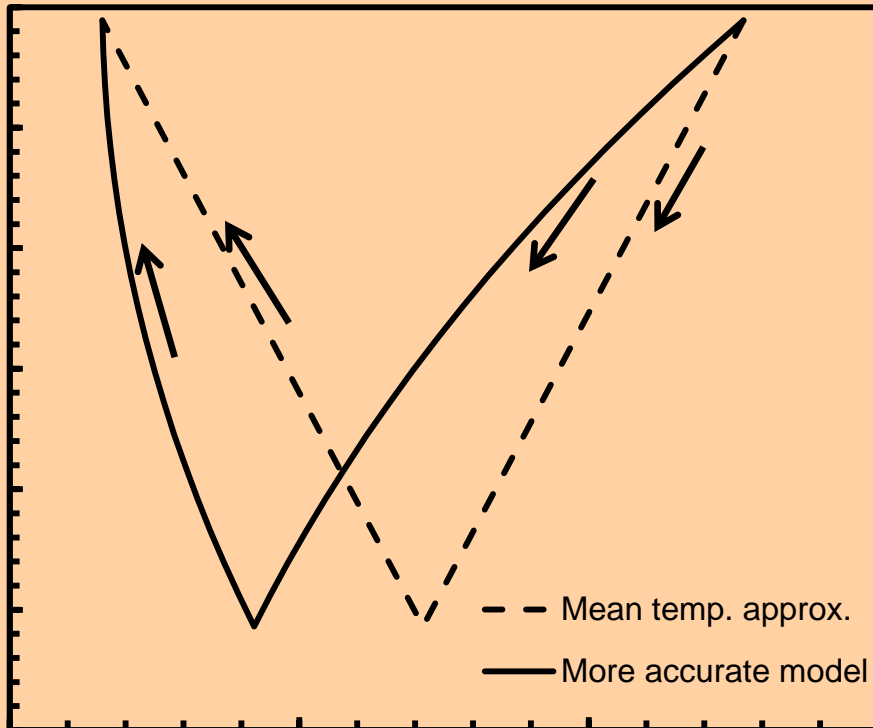


# Vertical Temperature Profiles Coaxial Heat Exchanger

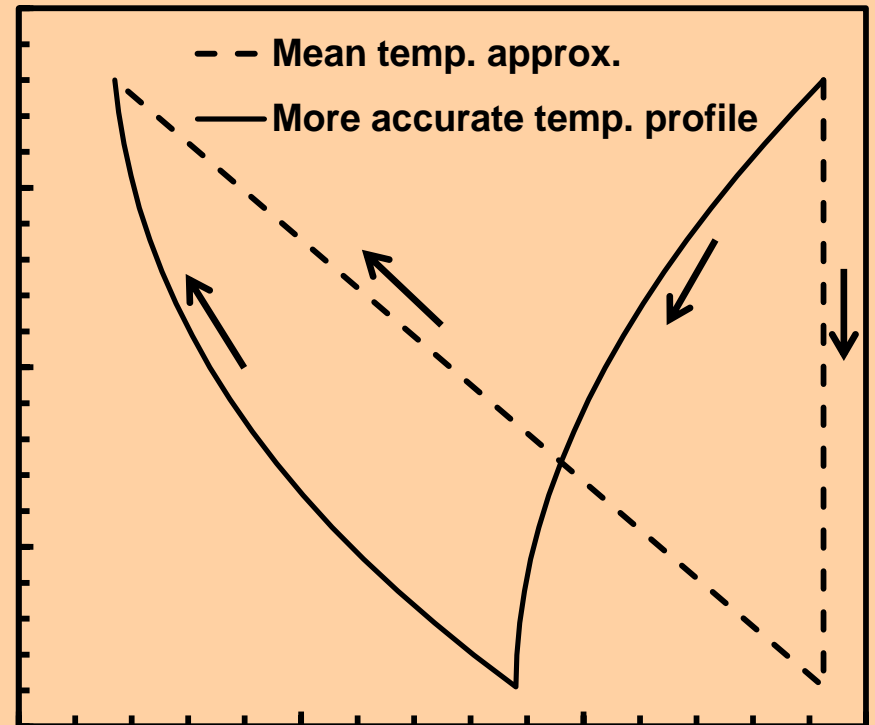


# Vertical Temperature Profiles

## U-tube



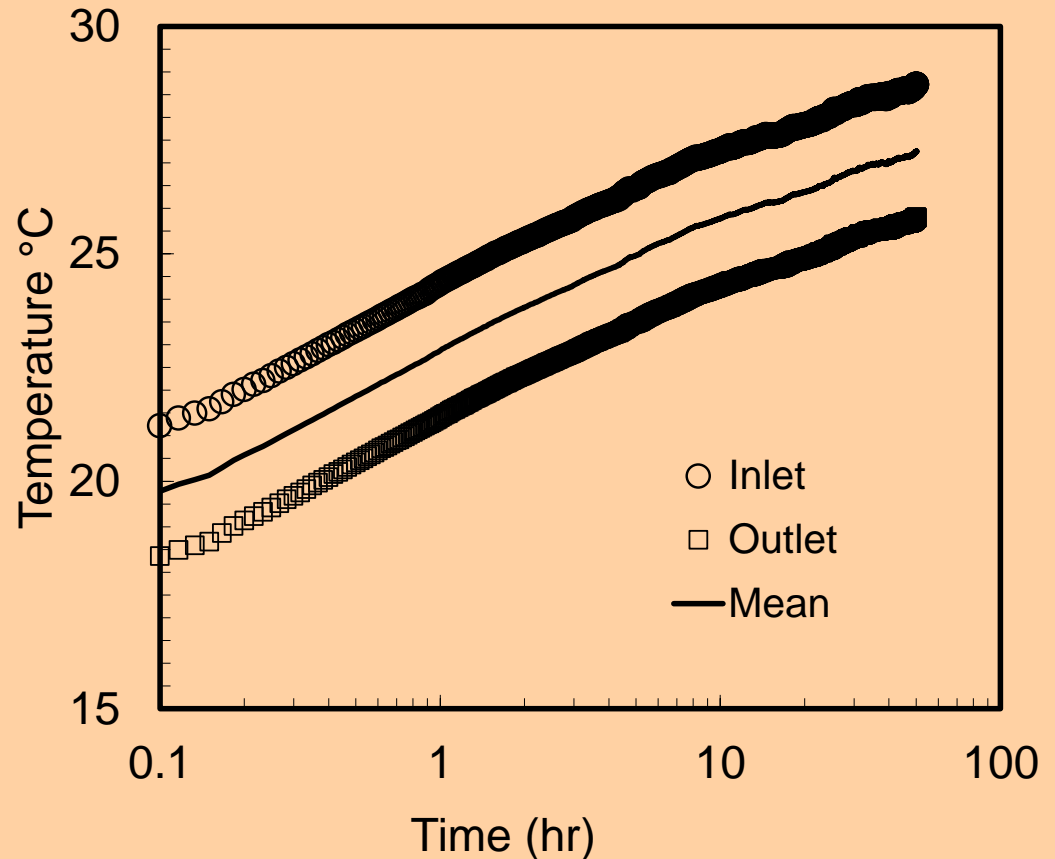
## Coaxial



# Mean Temperature Approximation

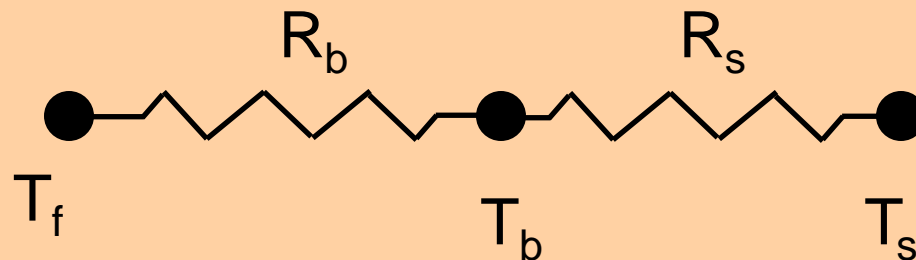
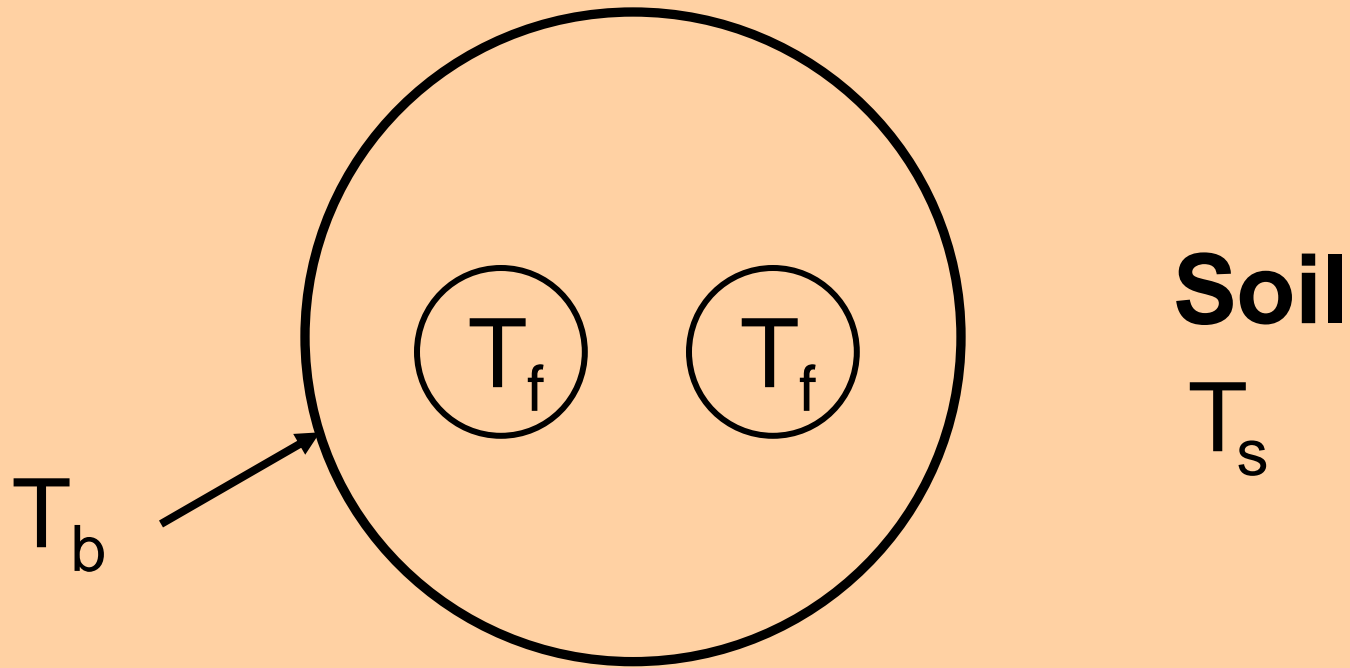
$k_s$  = soil thermal conductivity

$$k_s \sim \frac{1}{\text{late time slope}}$$



Estimated soil thermal conductivity  
not affected by approximation

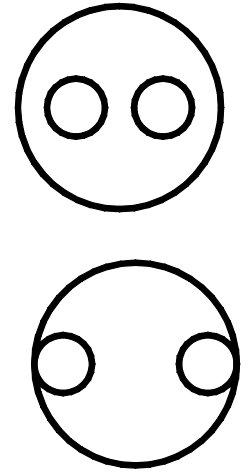
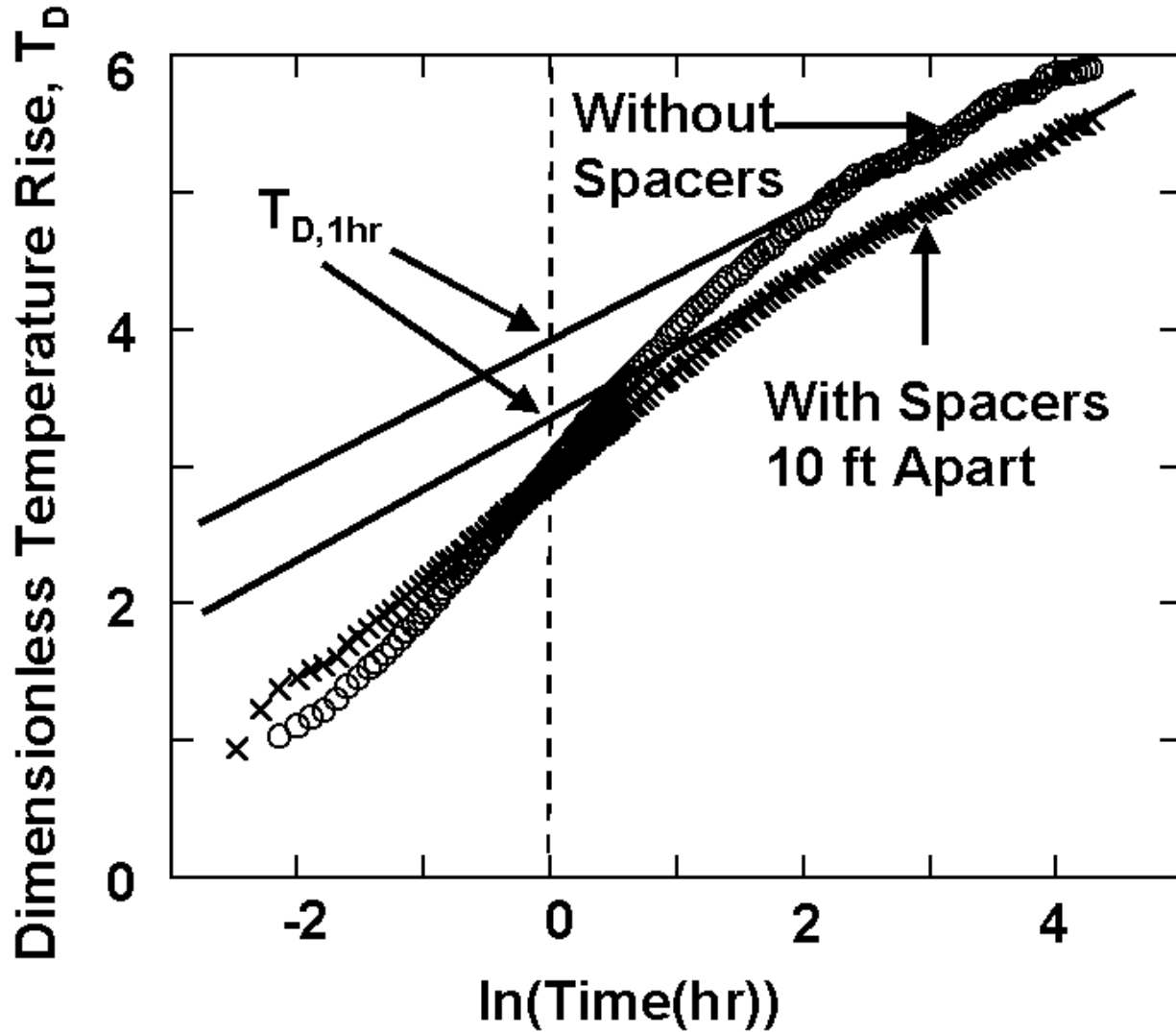
# Borehole Thermal Resistance, $R_b$



$$R_b = \frac{T_f - T_b}{q/L}$$

$$R_s = \frac{T_b - T_s}{q/L}$$

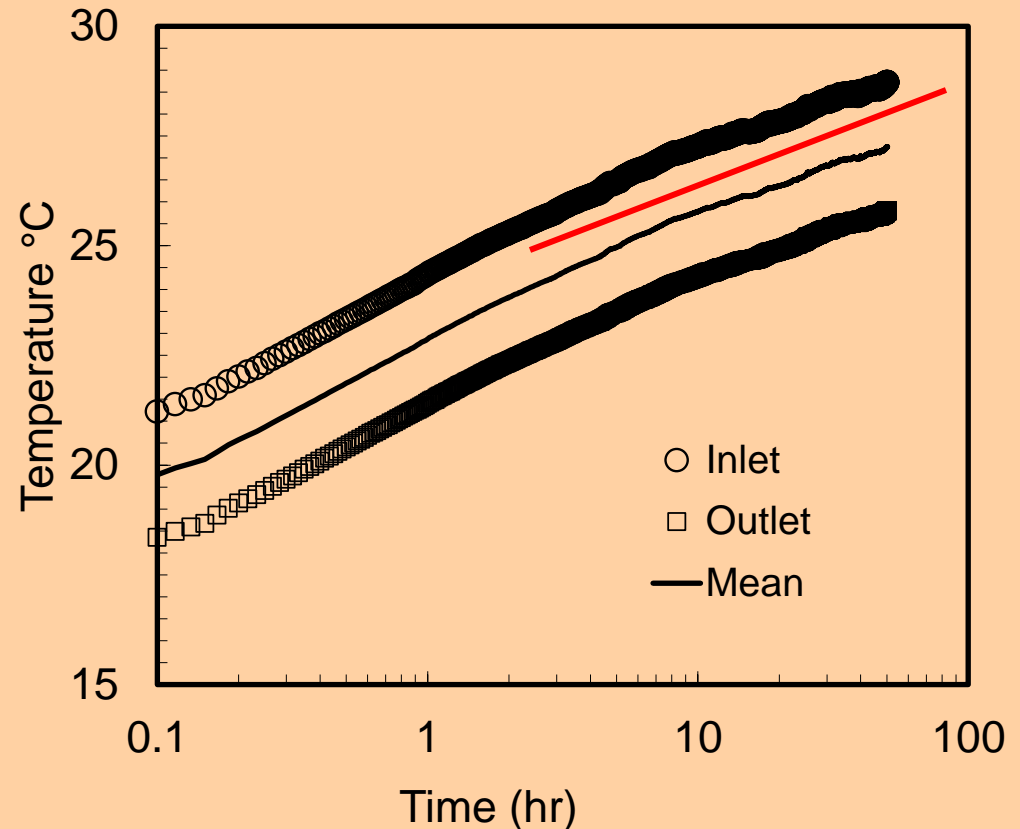
# Two Boreholes



# Mean Temperature Approximation U-tube

Vertical temperature averaging  
affects vertical offset

Estimated borehole thermal  
resistance depends on offset



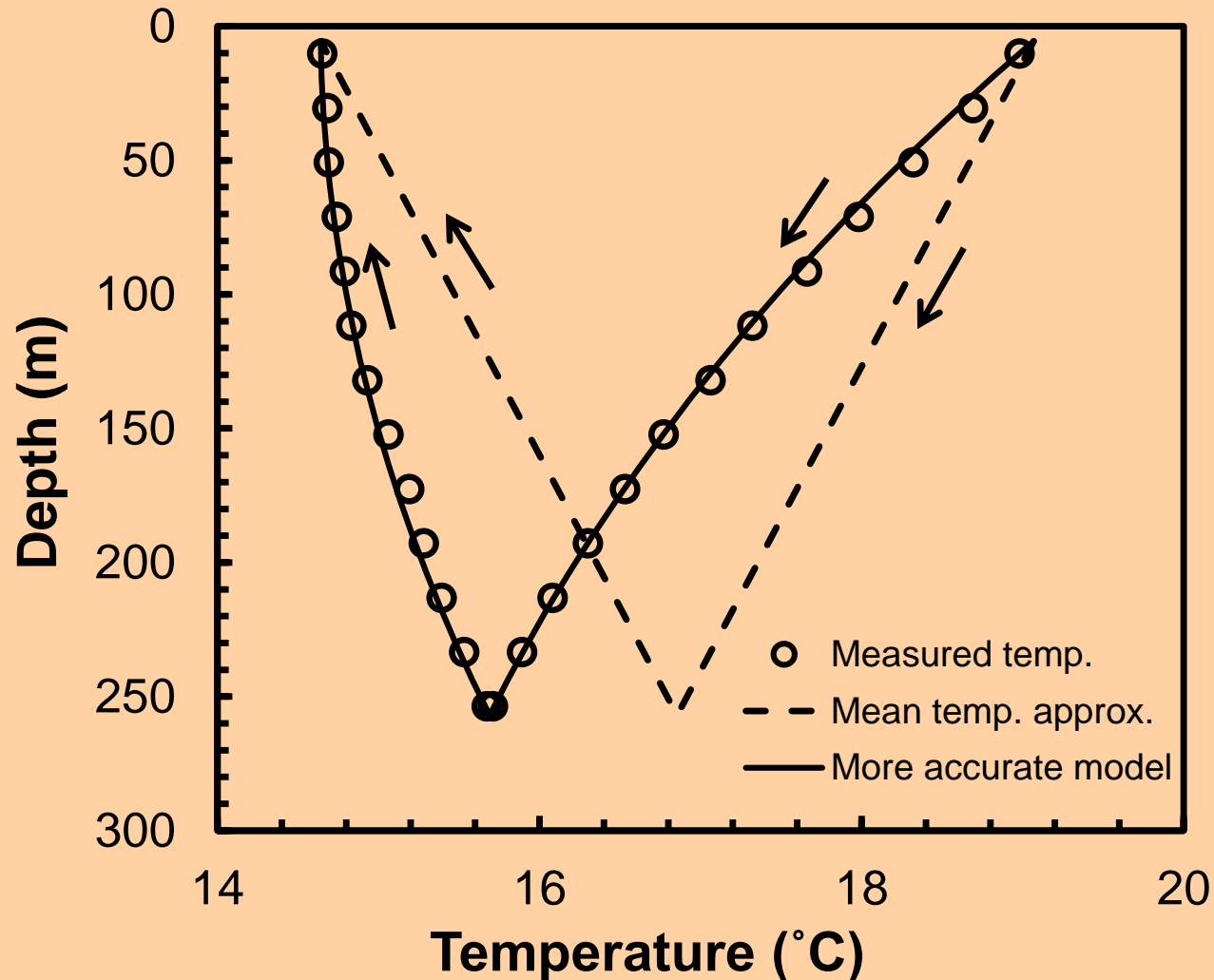
Estimated borehole resistance is  
affected by approximation

# Measured Vertical Temperature Profiles

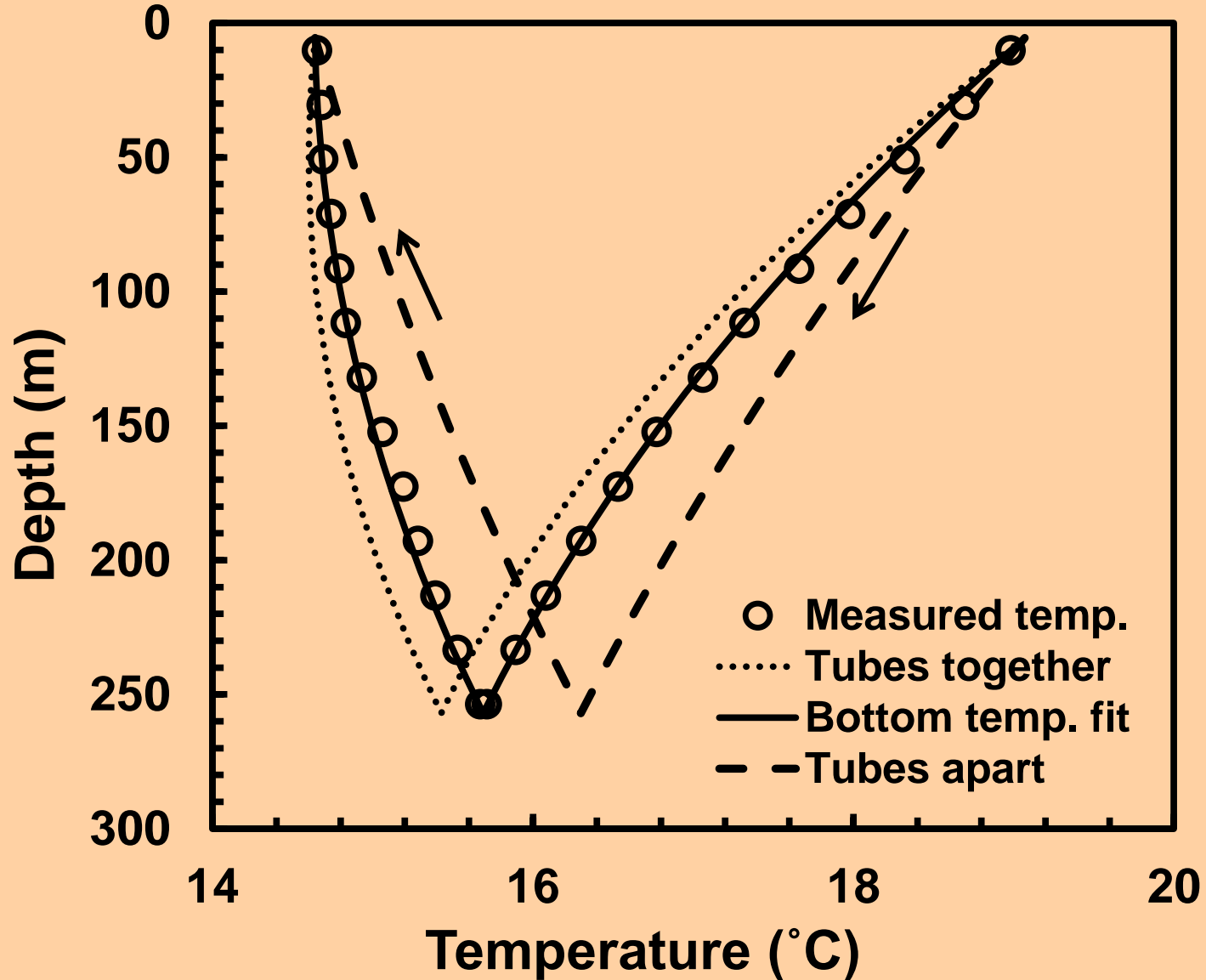
- Acuña, J. and Palm, B. at KTH Royal Institute of Technology, Stockholm, Sweden
- Temperature measurement by optical technique
- Fiber optical cable inserted inside U-tube

<http://www.kth.se/itm/inst/energiteknik/Forskning/ett/projekt/energibrunnar/publications-1.41084>

# Proposed Model Compared to Measured Vertical Temperature Profiles in U-tube



# Vary Distance Between Legs of U-tube



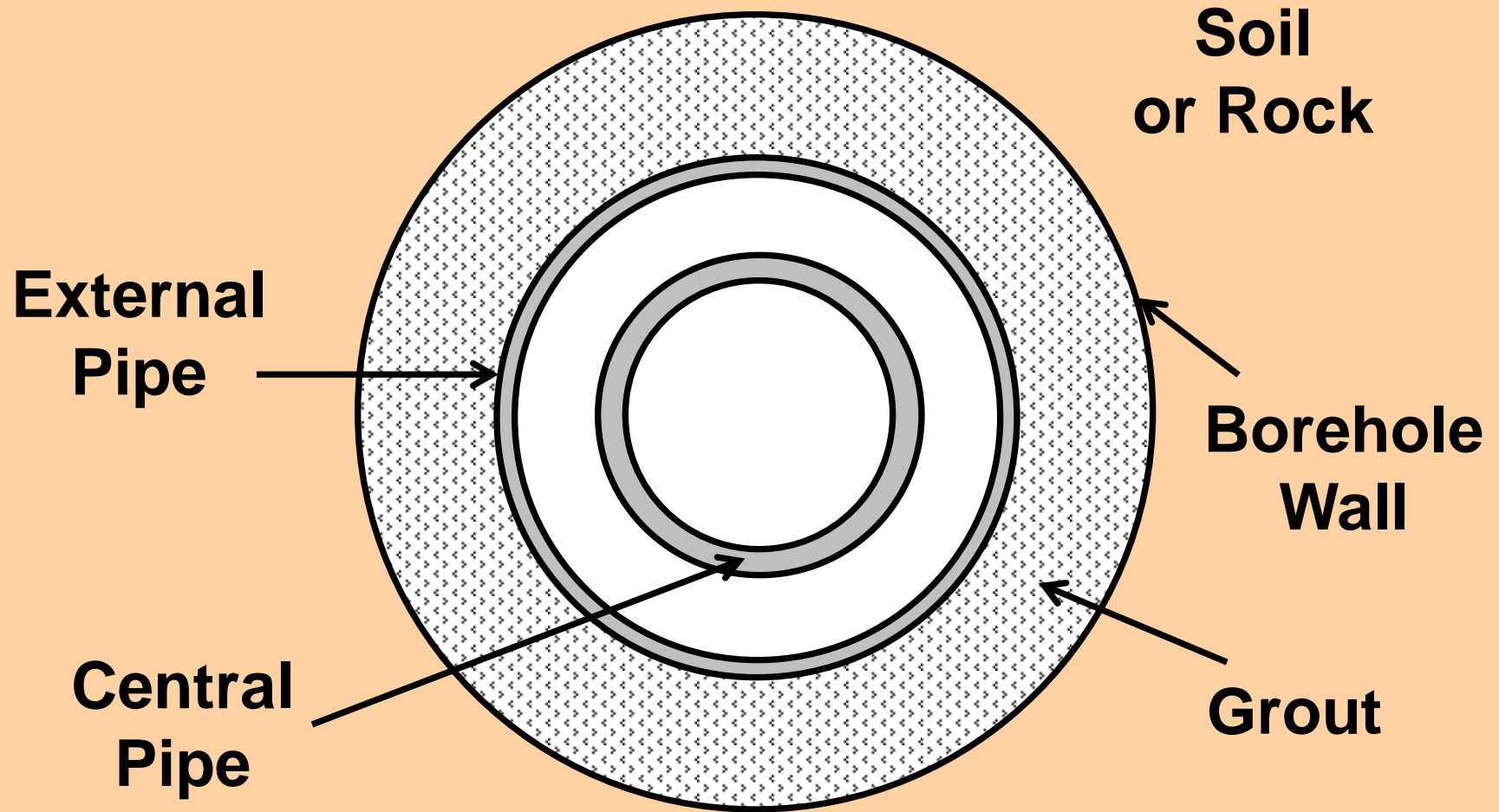
# Mean Temperature Approximation In-situ Test

- Error in borehole resistance estimate increases as borehole length,  $L$ , increases
- Error decreases as volumetric flow rate,  $w$ , increases
- Error decrease as thermal resistances increase

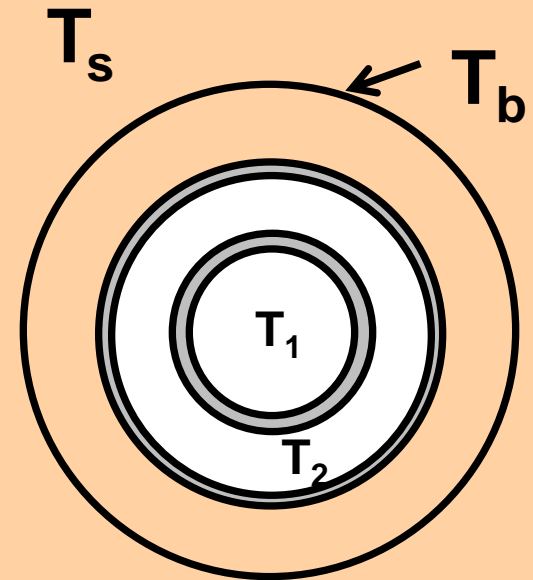
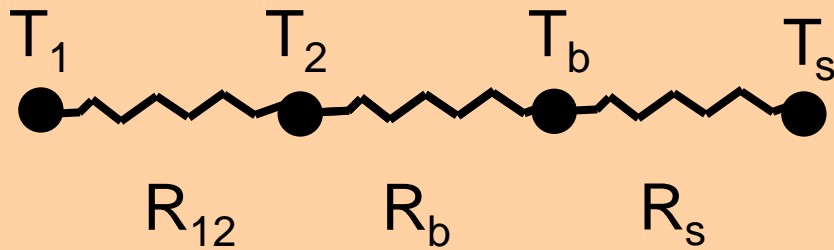
# Error in Mean Temperature Approximation With U-tube

- To keep error in total resistance (borehole plus soil) less than 5%
- Flow rate  $> 4$  gal/min for every 300 ft depth
- Or flow rate  $> 0.25$  liter/s for every 100 m depth
- Valid when water is circulating fluid

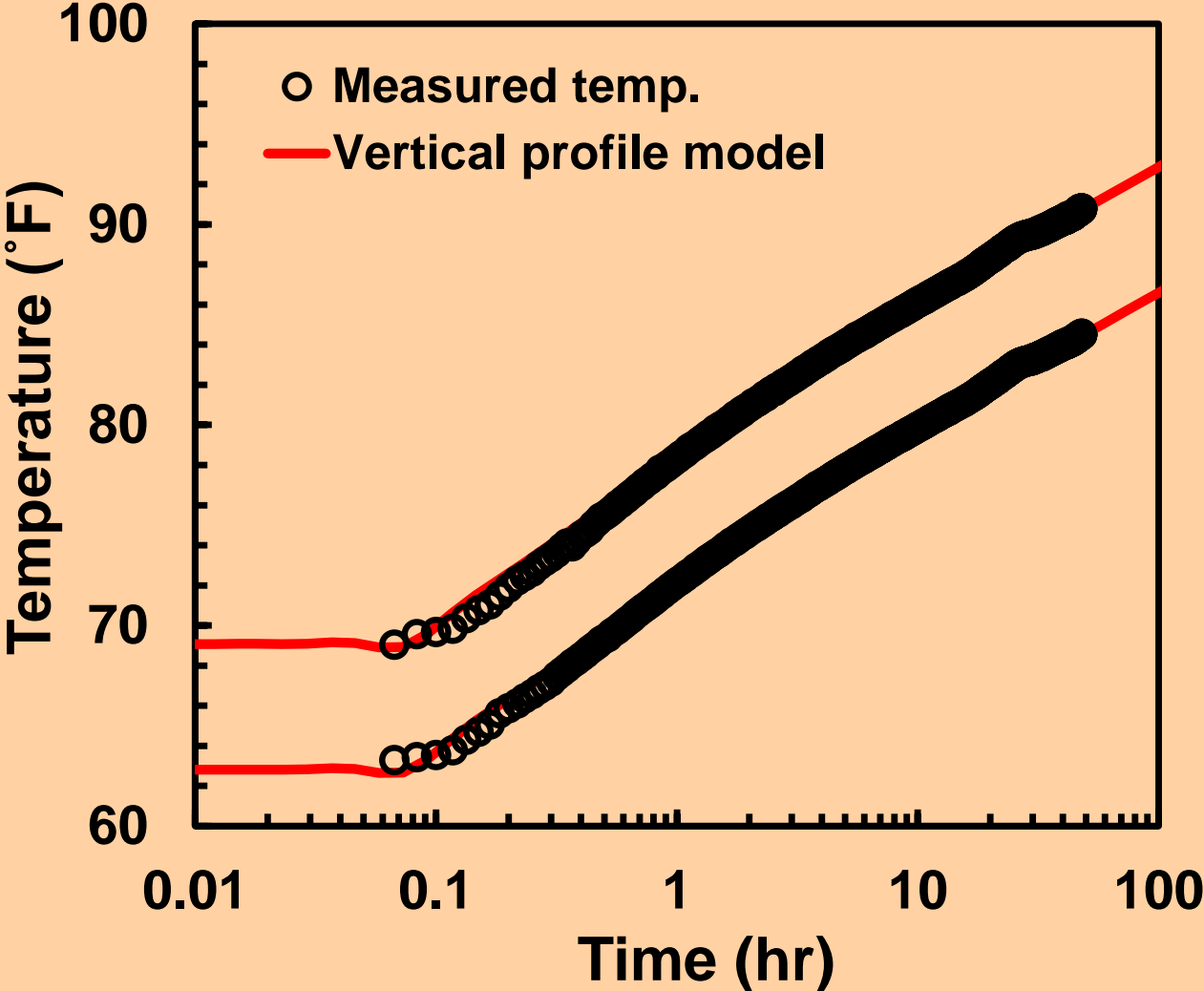
# Coaxial Heat Exchanger



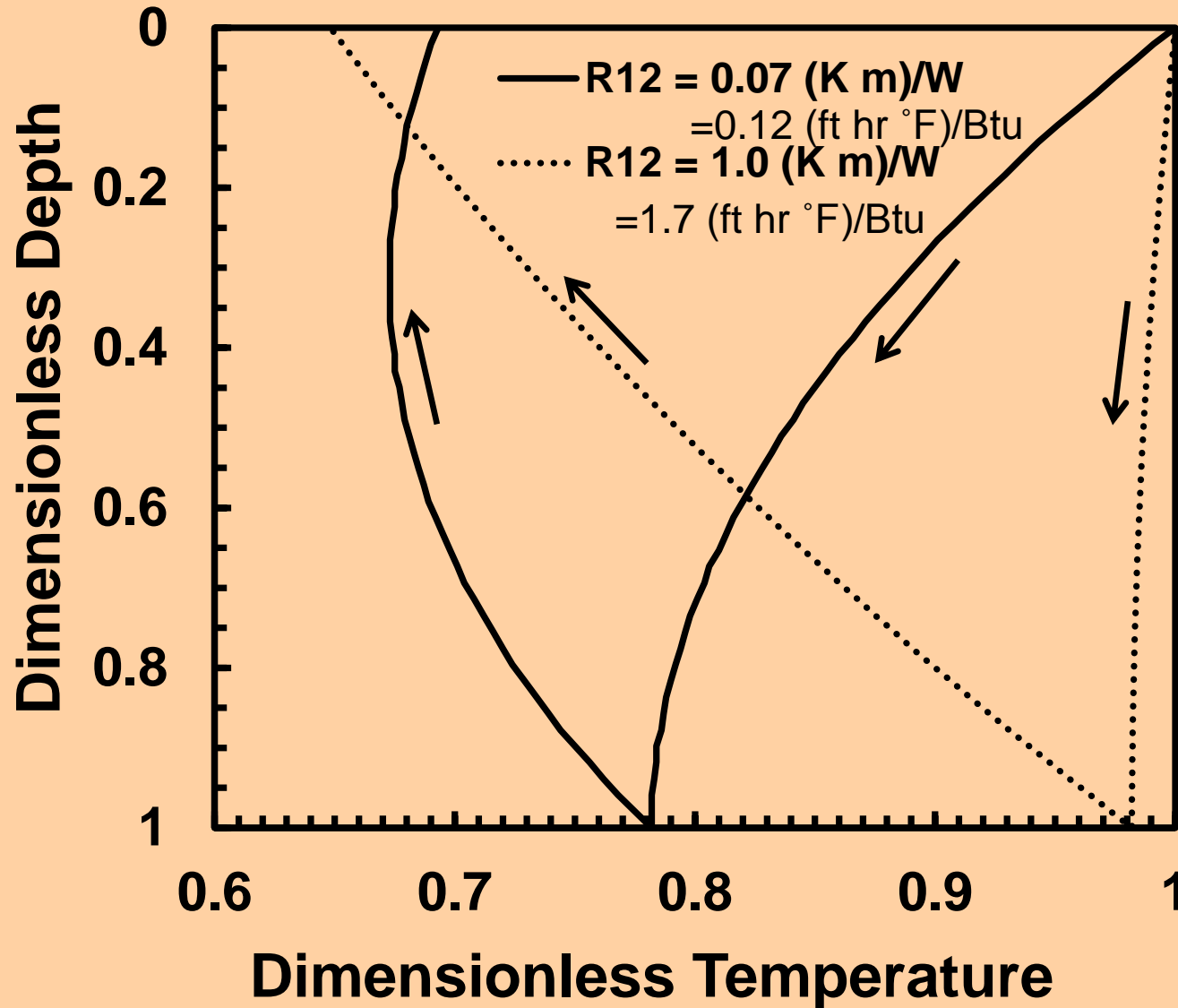
# Fluid enters the central pipe



# Model and Measured Temperatures Geothex®



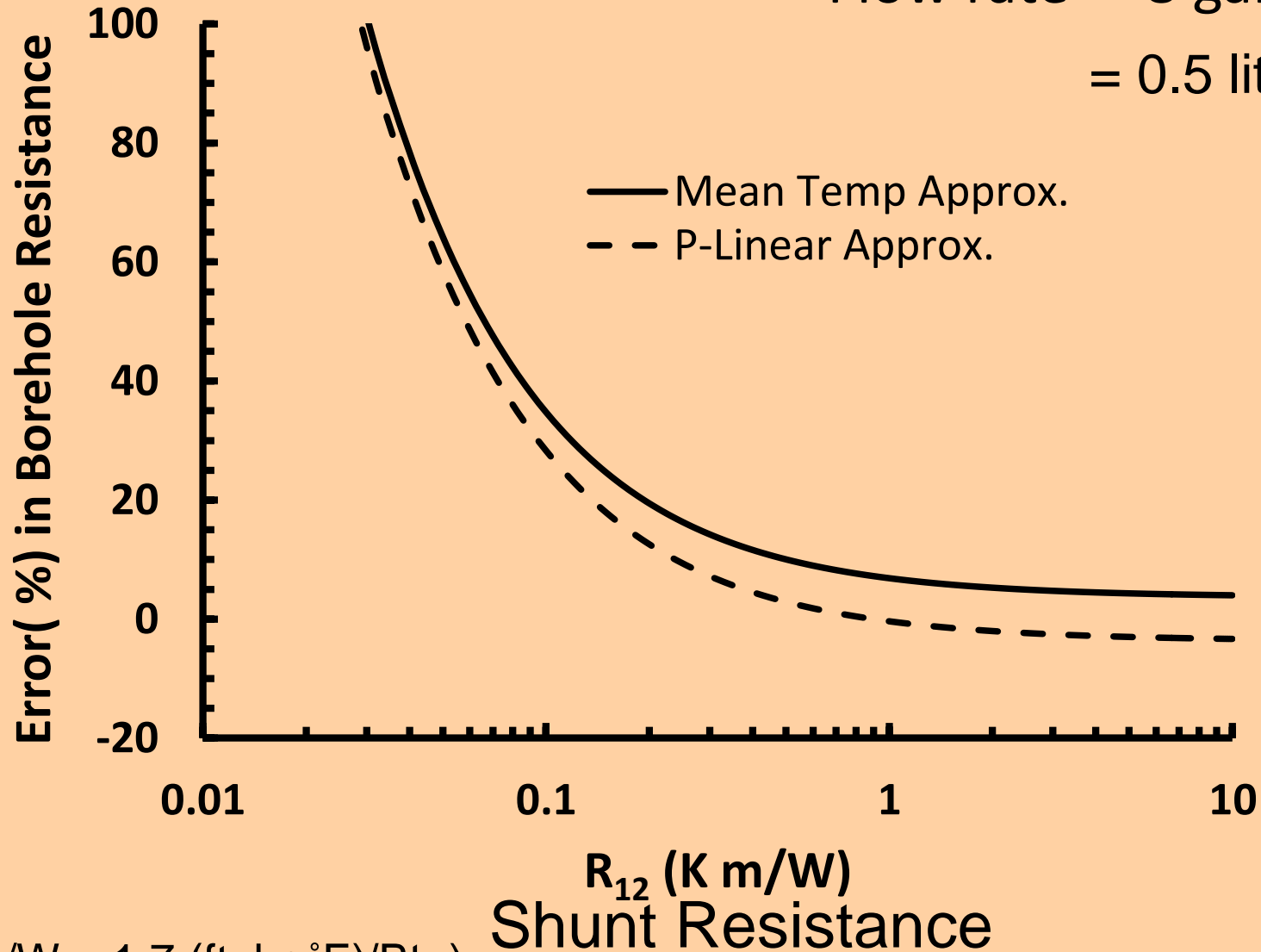
# Vary Shunt Resistance



# Mean Temperature Approximation

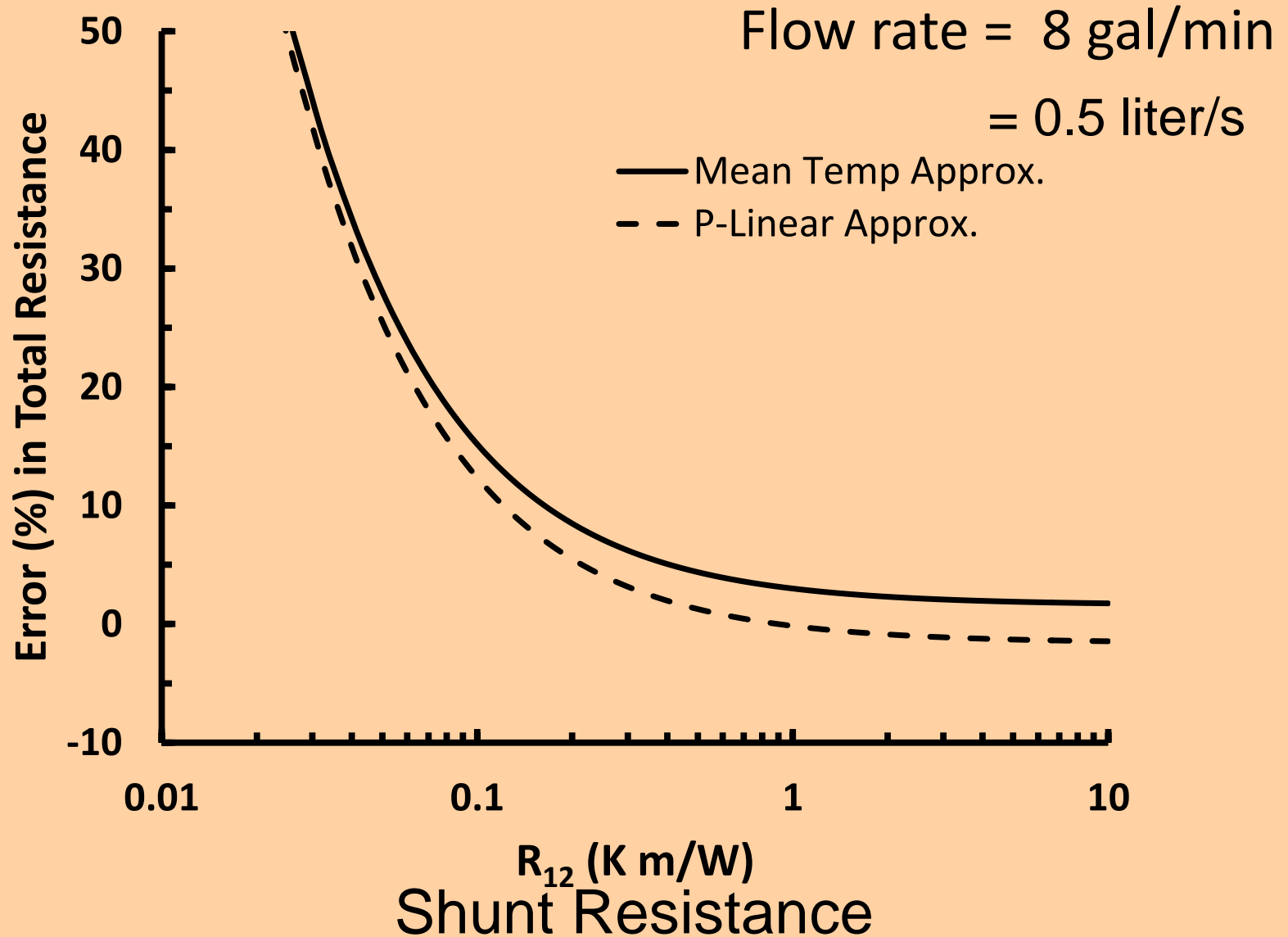
Flow rate = 8 gal/min

= 0.5 liter/s



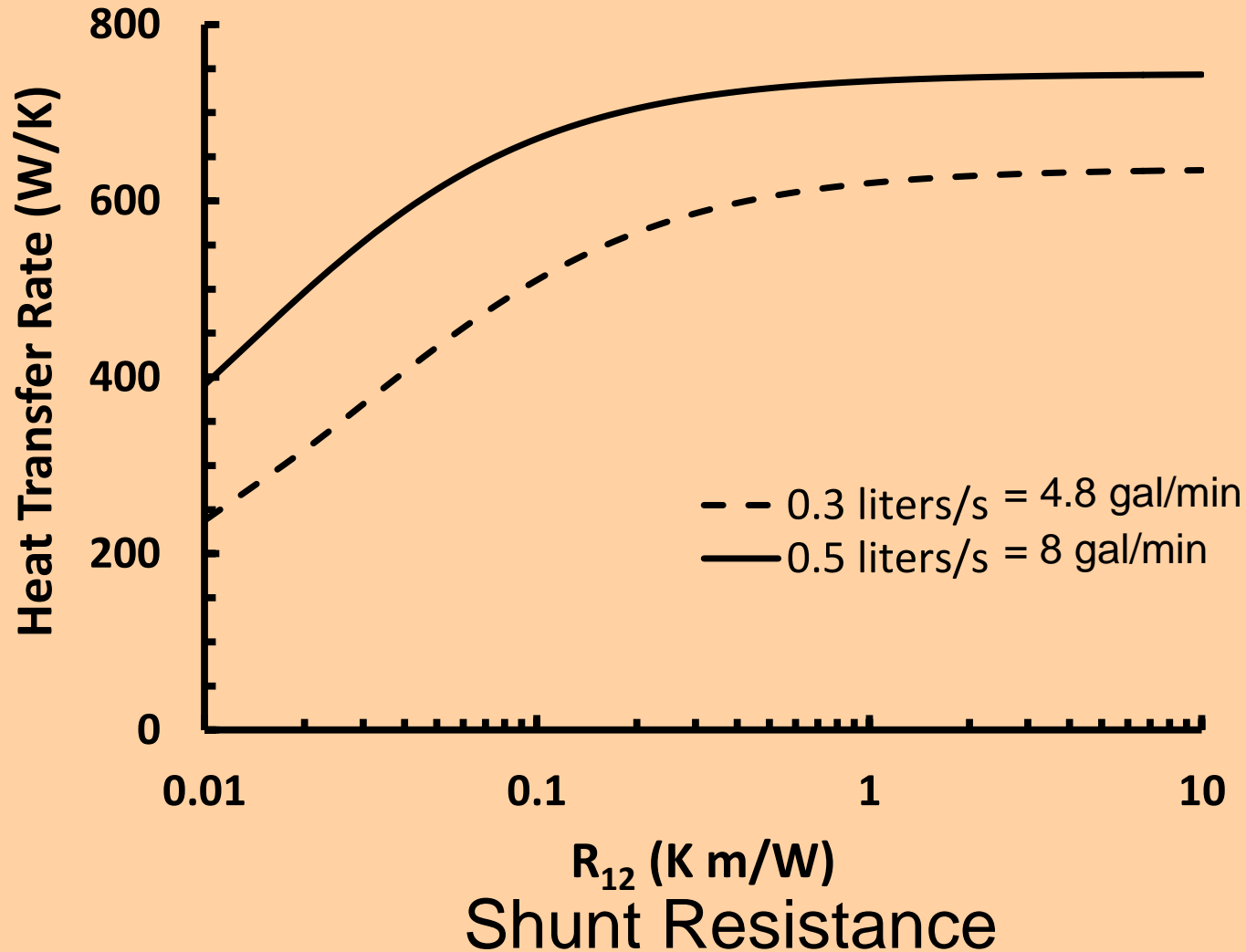
1 (m K)/W = 1.7 (ft hr °F)/Btu)

# Mean Temperature Approximation



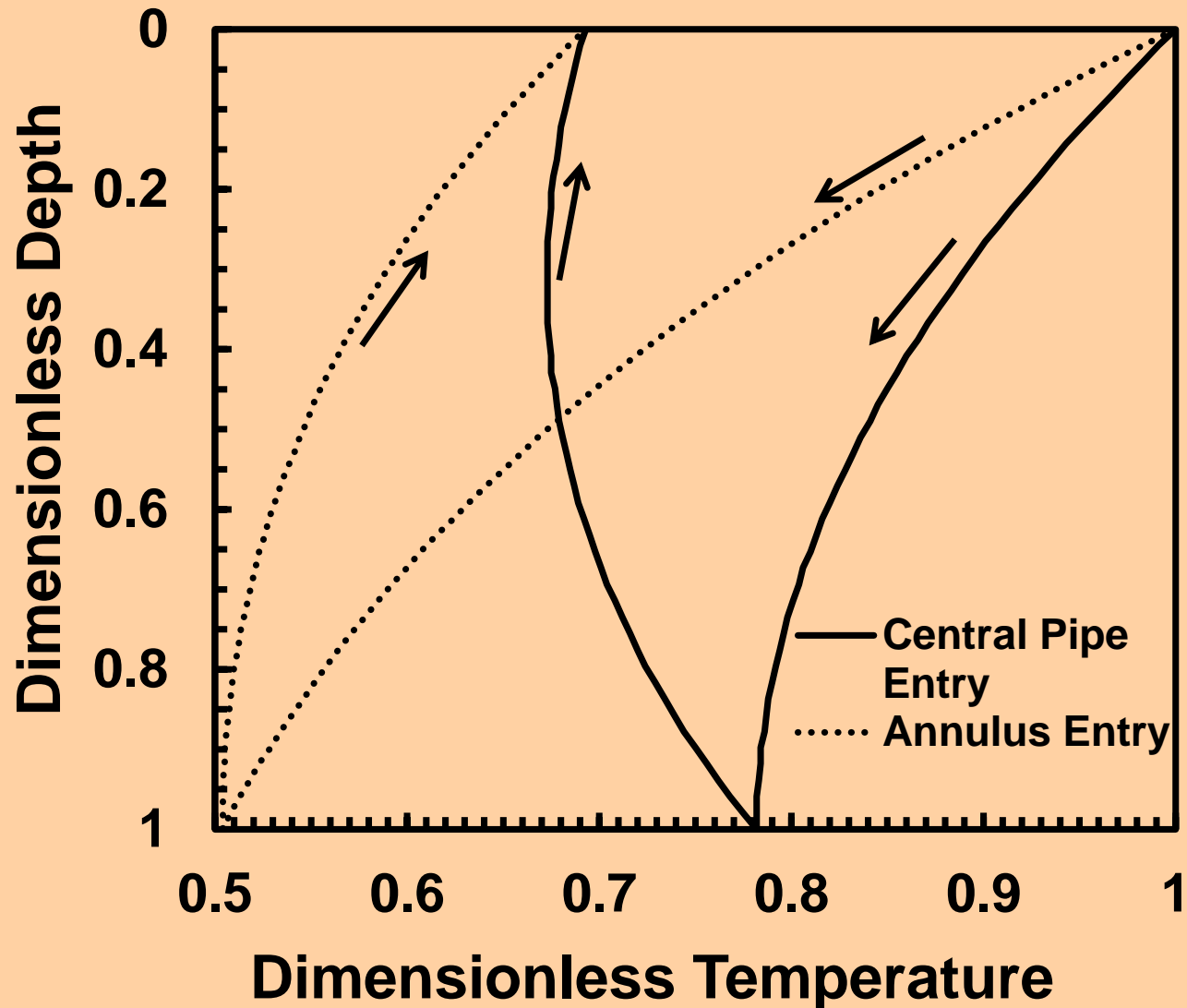
1 ( $\text{m K}/\text{W}$ ) = 1.7 ( $\text{ft hr } ^\circ\text{F}/\text{Btu}$ )

# Heat Transfer Rate To Ground As Shunt Resistance Varies



1 (m K)/W = 1.7 (ft hr °F)/Btu)

# Change in Flow Direction



# Design Software

- Thermal resistance estimate used by design software
- Design software programs often use mean temperature approximation
- Mean temperature approximation expected to give little error if flow rate and depth are unchanged from in-situ test
- Test analysis and design should have consistent assumptions

# Design Software

- Vertical temperature profile model provides more rigorous estimate of borehole resistance
- Design under full range of different lengths and flow rates

# Conclusions

- Models developed for vertical temperature profiles in borehole
- Limitations of mean temperature approximation in estimating borehole resistance from in-situ tests
- For U-tube -- Errors ( $< 5\%$ ) borehole if flow rate  $> 4$  gal/min for every 300 ft depth

# Conclusions

- Coaxial boreholes – Thermal resistance of inner pipe greatly affects validity of approximation
- Coaxial boreholes – Approximation more valid for insulated inner pipe wall