THERMAL RESPONSE TESTING: DEVELOPMENT AND PRACTICE

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My Background

- Mechanical Building Services, Arup
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More Comments on In-situ Borehole Thermal Conductivity Testing

By Jeff Spitler, Simon Rees, and Cenk Yavuzturk; Oklahoma State University

Two recent articles (Skouby 1998, Smith 1999a) in *The Source* have discussed in-situ thermal conductivity testing. For very practical reasons, there is one hot button issue related to in-situ thermal conductivity testing—how long should the test be? The authors have recommended 50 hours as a minimum test length. Yet, we are well aware that a shorter test would be highly desirable even if some small, but acceptable, loss of accuracy resulted. This article is aimed at explaining how and why we came up

numerical model of the borehole and surrounding ground so as to minimize the differences between the actual temperature response and the model-predicted temperature response. The ground thermal conductivity that gives the minimal difference between the two responses is the estimated value.

With parameter estimation, any number of parameters might be estimated simultaneously. Initially we attempted

Spitler, J.D., S.J. Rees, C. Yavuzturk. 1999. More Comments on In-situ Borehole Thermal Conductivity Testing. The Source. Vol. 12, No. 2, March/April 1999. pp. 4-6

Outline

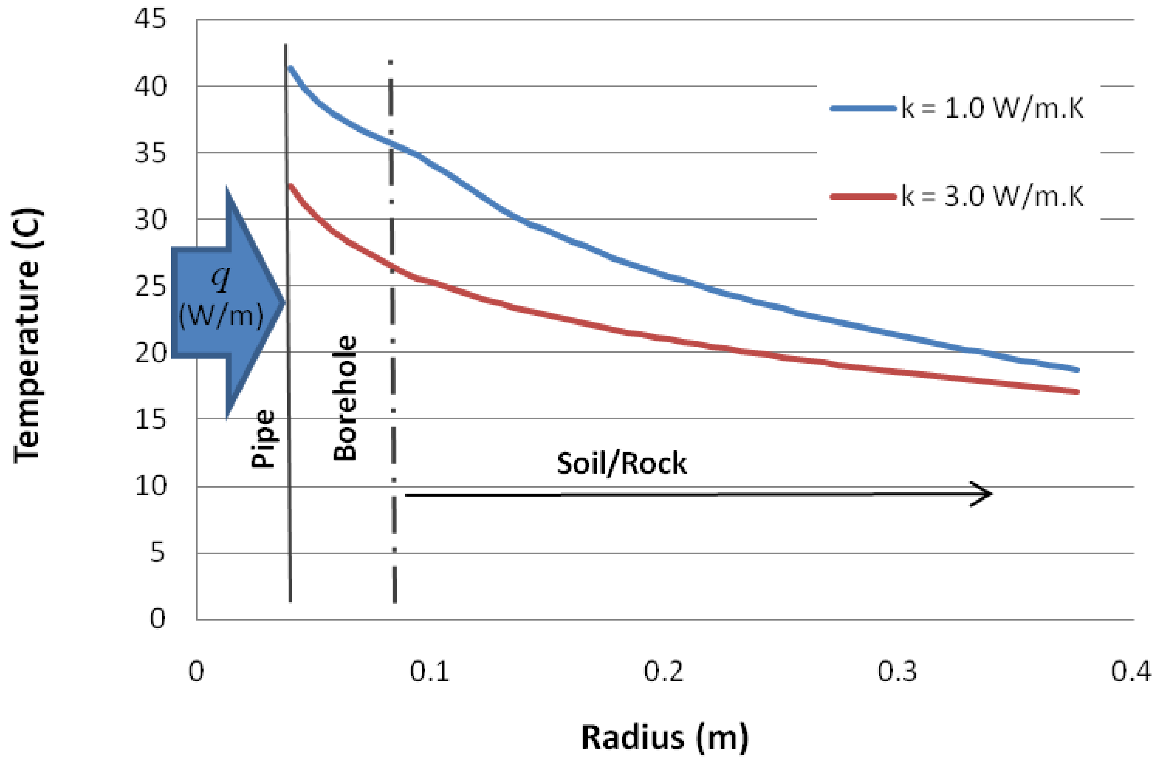
- Why do we need Thermal Conductivity data?
- Basic principles and equipment
- Basic analysis methods
- Parametric analysis methods
- How well does it work?

ESSENTIAL DESIGN INFORMATION

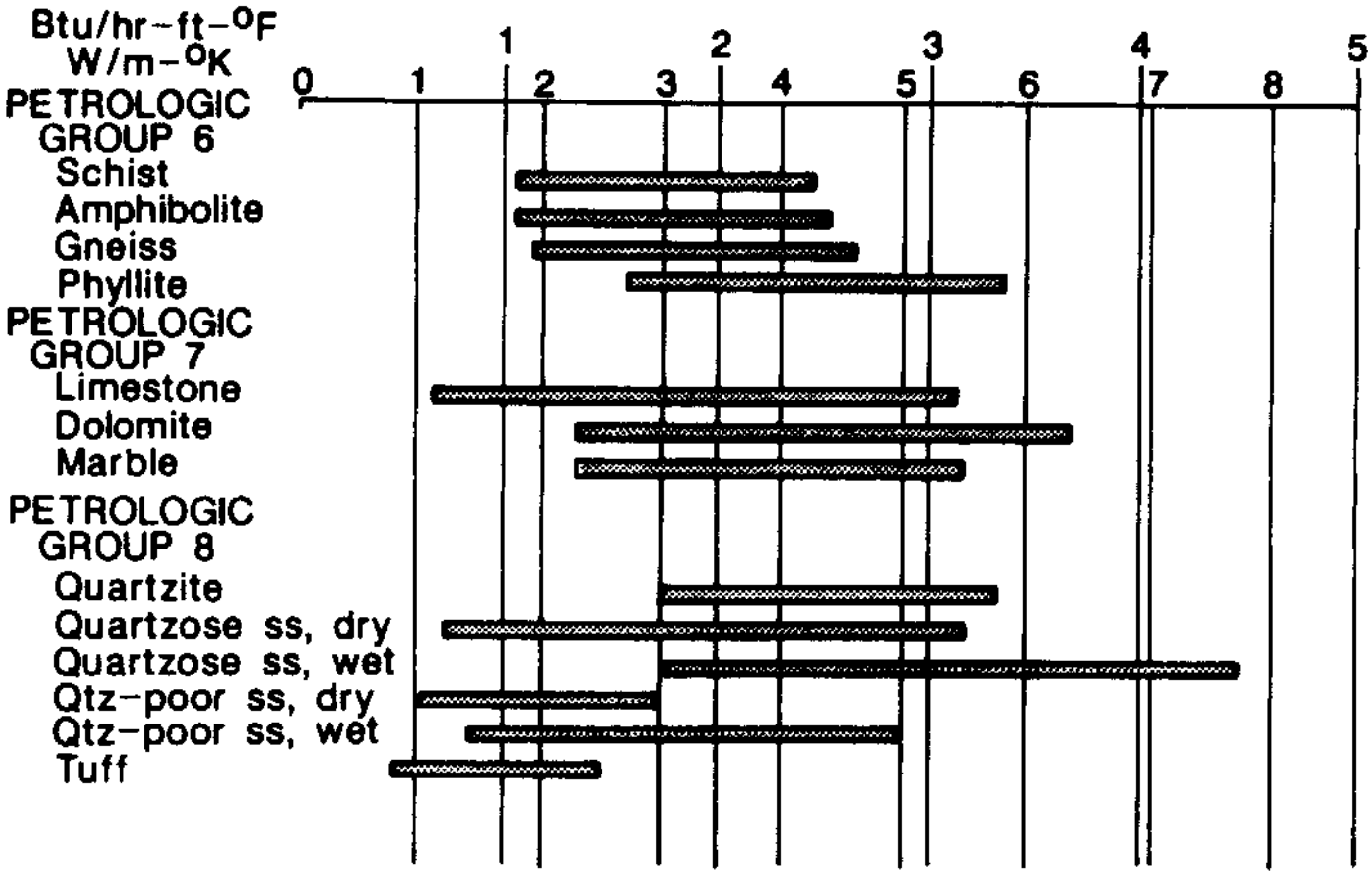
- Building Loads – monthly and peaks
- Ground initial temperature
- Borehole thermal resistance – diameter, grout properties, flow rate and pipe size/spacing
- Ground thermal conductivity (effective)

Why Does Conductivity Matter?

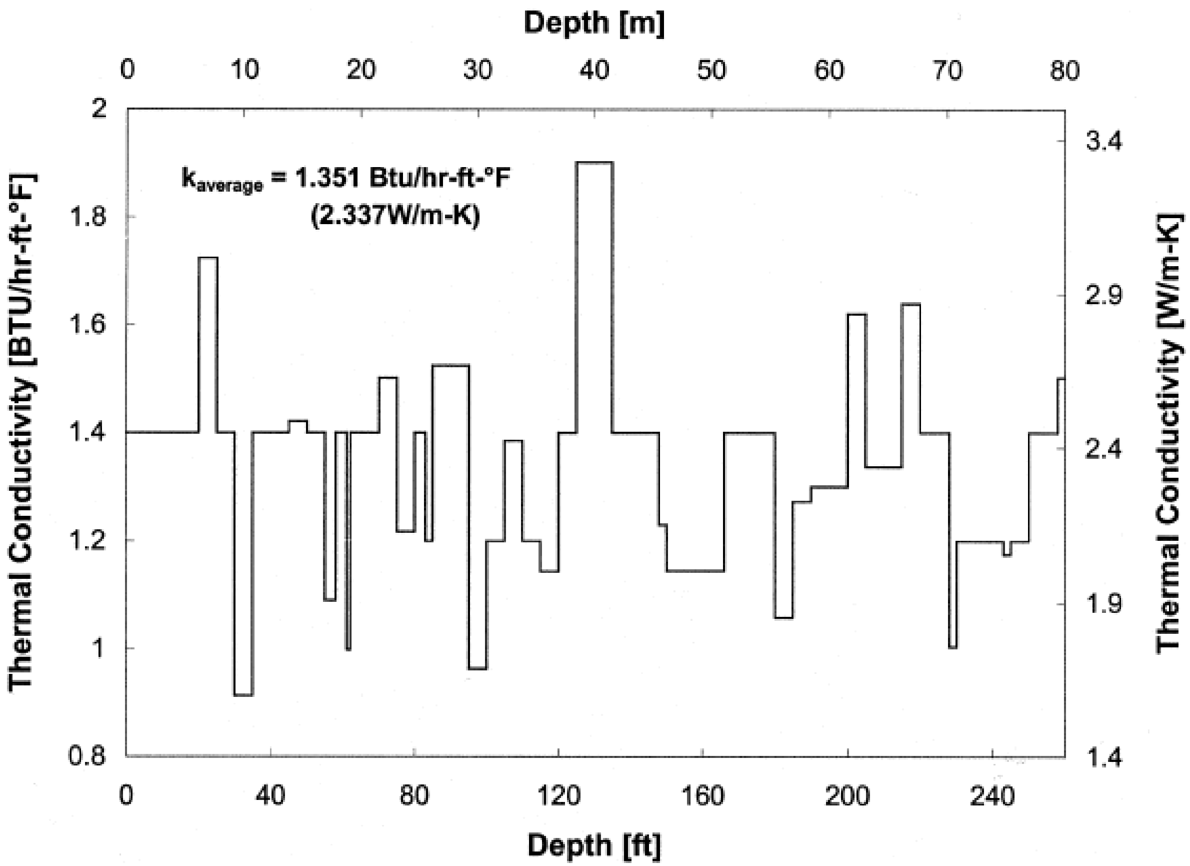
Thermal conductivity has a very direct effect on peak temperature and hence borehole field size (cost).



ROCK AND SOIL THERMAL PROPERTIES



THERMAL CONDUCTIVITY DATA



WHY TEST?

- You can’t design without conductivity data
- Reference and desk-top study data only has broad ranges of values
- Careful testing should give values +/- 10%
- Risk management – cost *vs* risk
  - Estimate too low and cost may be excessive
  - Estimate too high and system will be at risk of failure
- Big sites may justify more than one test

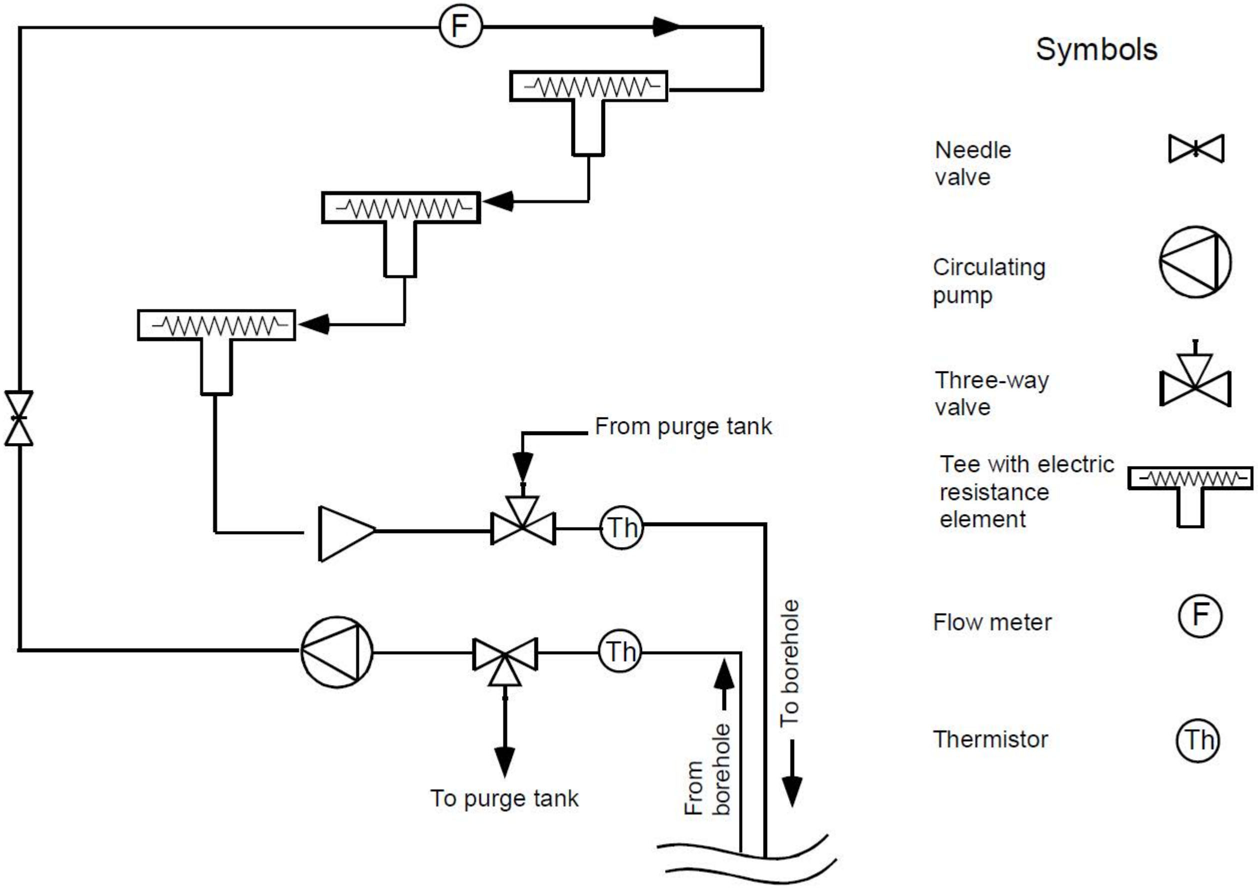
THE THERMAL RESPONSE TEST CONCEPT

- Drill a test borehole and complete with U-tube of expected size.
- Flush and fill with fluid
- Leave the tube and fluid to stabilize – several days.
- Investigate the initial temperature
- Put a heat flux on the borehole:
  - Usually in-line electrical heating elements
  - Heat pump (heating and cooling)
  - Gas fired heater
- Temperature response can be used to estimate ground thermal conductivity.
- Other information – initial ground temperatures, borehole resistance and indications of groundwater flow. Drilling conditions?

What To Measure

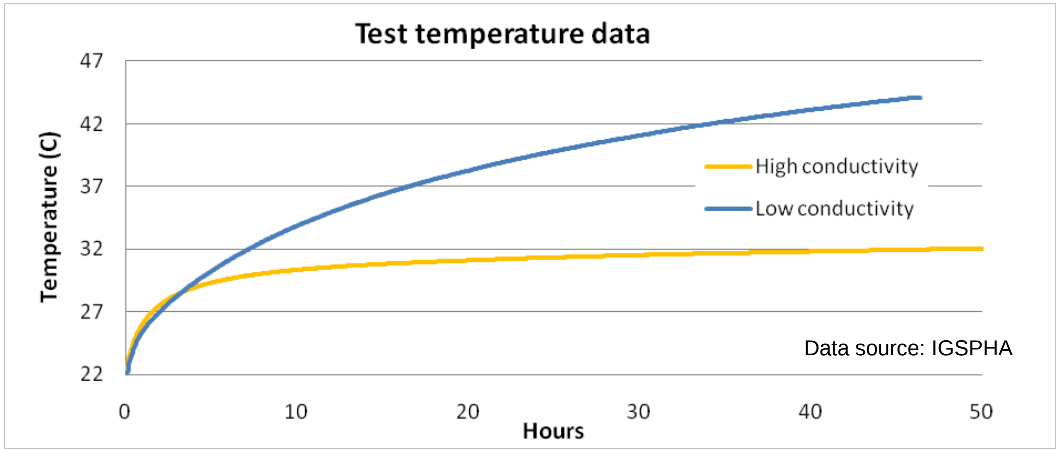
- Initial temperatures – probe or initial fluid temperatures
- Flow and return temperatures
- Flow rate
- Power input – continuous monitoring:
  - Electrical
  - Calculated later from flow rate and temperature differences
- How Long? The usual recommendation is minimum of 50 hours. The longer the better.
- Ambient temperature
- Automatic logging – often minutely
- Proper calibration is important

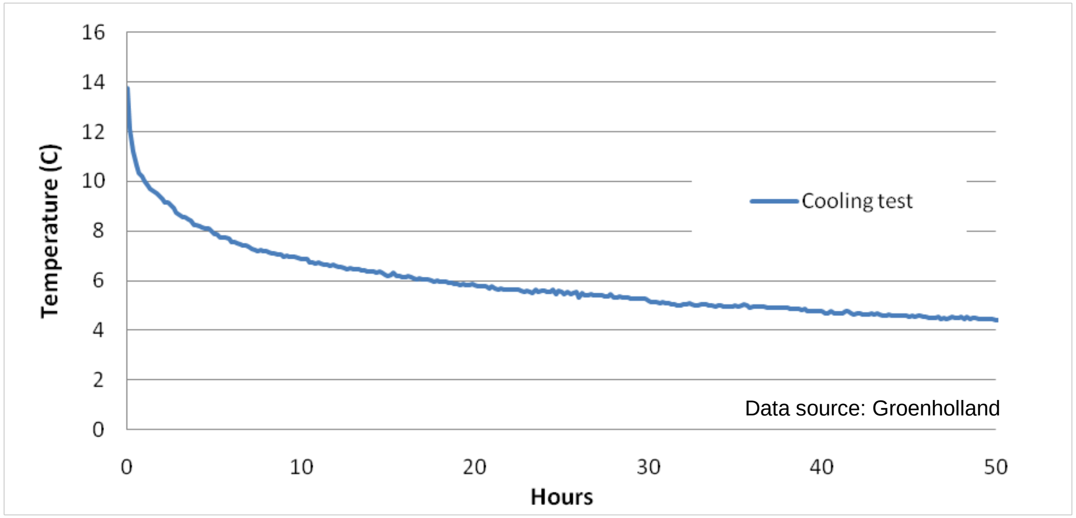
In Situ Measurement



TYPICAL RESPONSES

The key data needed for analysis is the average fluid temperature and power input



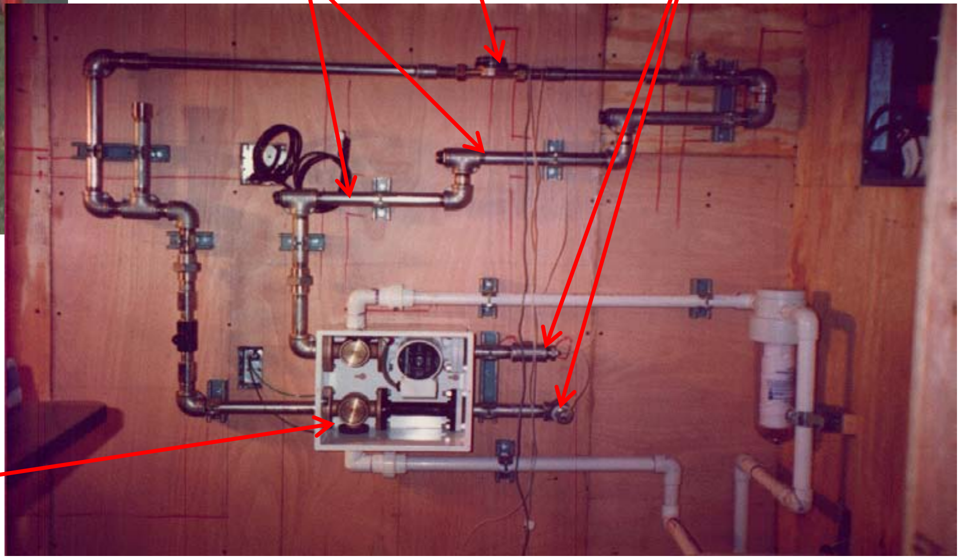


RESEARCH EQUIPMENT

Electric heaters (3 x 3kW)

Flow meter

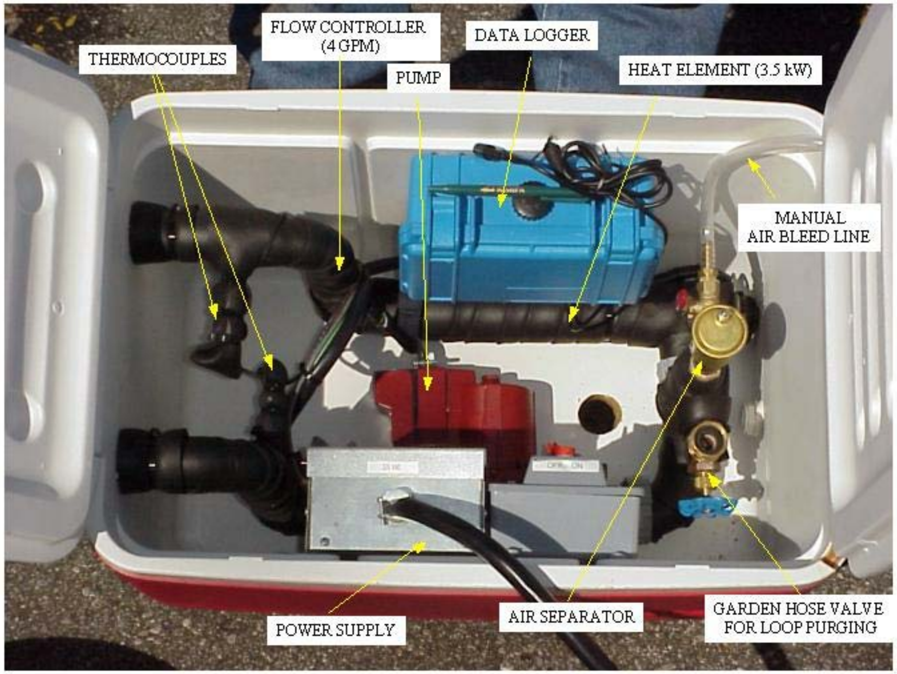
Flow/return temp. sensors



Pumps and purge valves

Photos: J.D. Spitler

Compact Site Equipment



Generator not shown !

Photos: A. Chaisson

ANALYSIS PROCEDURES

- Line source analytical solution:
  - Simple, conductivity is proportional to slope of temperature rise *vs* ln(t)
  - Requires <u>very</u> constant power input
- Parameter estimation-based procedures
  - Requires numerical model; more complex
  - Can handle varying power.

The Line Source Approximation

$$T_f = \frac{Q}{4\pi kD}\ \ln(t) + \left(\frac{Q}{D}\ \left(\frac{1}{4\pi k}\ln\left(\frac{4\alpha}{{r_b}^2}\right) - \gamma\ \right) - R_b\right) + \ T_g$$

time varying

constant

$$T_f = s \times \ \ln(t) + \ C$$

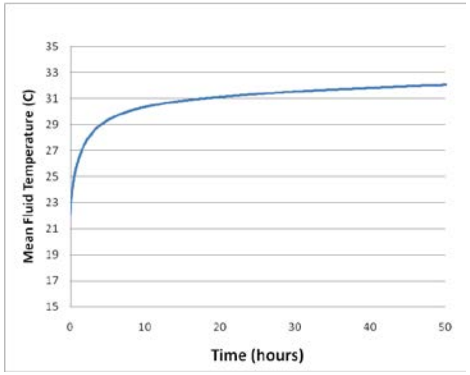
$$k = \frac{Q}{4\pi sD}$$

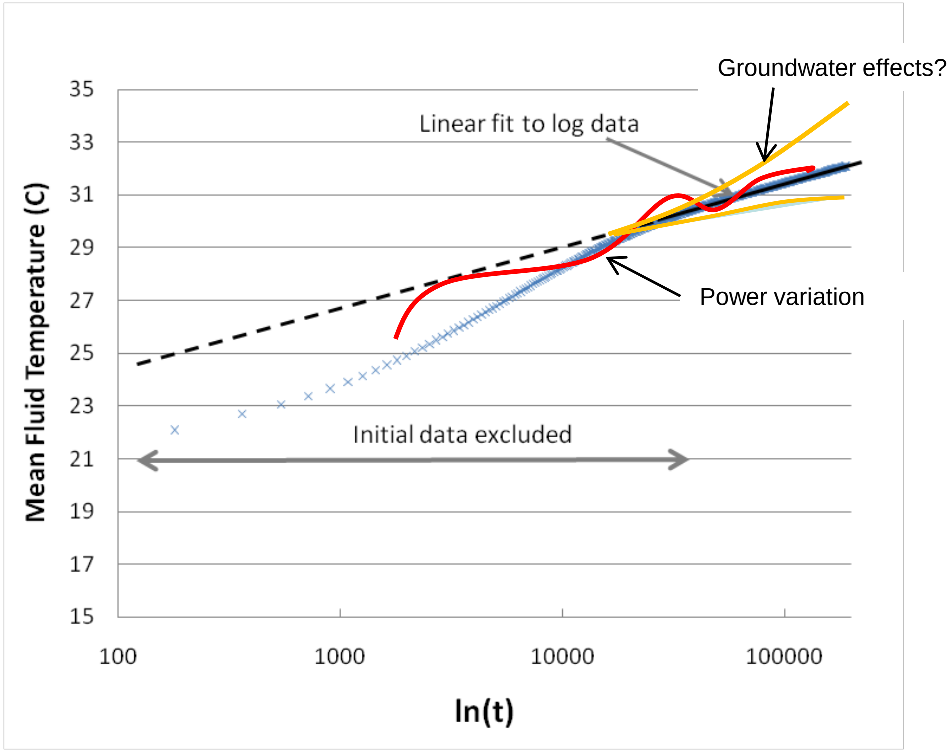
Where *S* is the slope of the temperature *vs* natural log time plot

T_f	= Circulating fluid mean temperature	r_b	= Borehole radius
Q	= Power supplied to circulating fluid (W)	R_b	= Thermal resistance (K/(W/m))
k	= Thermal conductivity	T_g	= Undisturbed temperature of the ground
t	= Time	D	= Effective borehole depth
γ	= Euler's constant (0.5772)	α	= Thermal diffusivity (m^2/s)

SPREADSHEET ANALYSIS

1. Plot temperature *vs* natural log of time
2. Find the slope – ignoring some early data
3. Use the slope to derive the effective conductivity



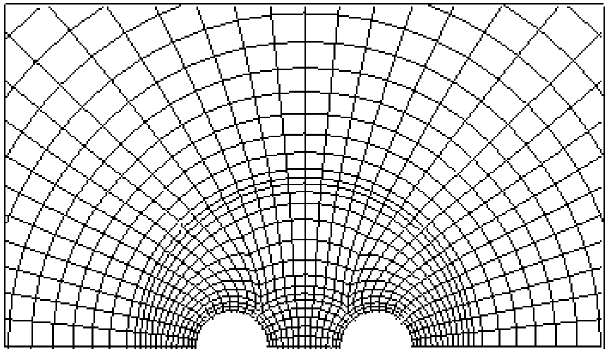


Parametric Numerical Methods

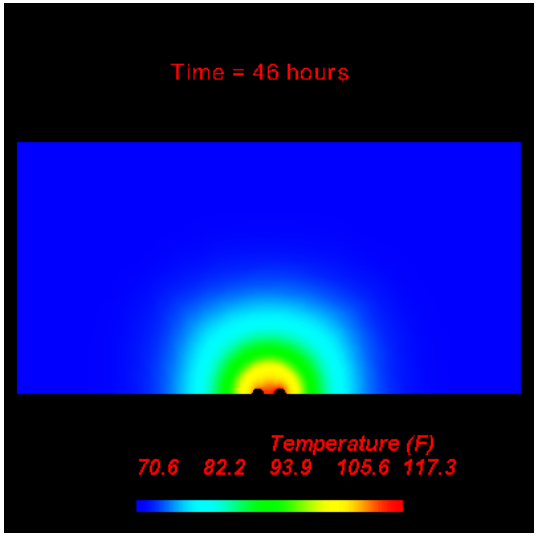
- The inverse heat transfer problem is solved using a series of numerical simulations of the test conditions:
  - measured power is input
  - fluid temperatures are calculated
- An automated parameter estimation algorithm is used to find the model conductivity values so that the model temperatures best match the test data
- Variables estimated can be density and specific heat but usually soil and grout thermal conductivity

The Numerical Model

- A two-dimensional model based on the Finite Volume Method
- The borehole geometry is represented in a boundary fitted mesh
- The pipe, grout and ground materials are explicitly represented in different zones of the mesh
- A transient calculation is made using the test heat flux as a boundary condition
- Ground, grout and pipe temperatures are calculated to mimic the test
- Average fluid temperatures are derived from the calculated pipe temperatures

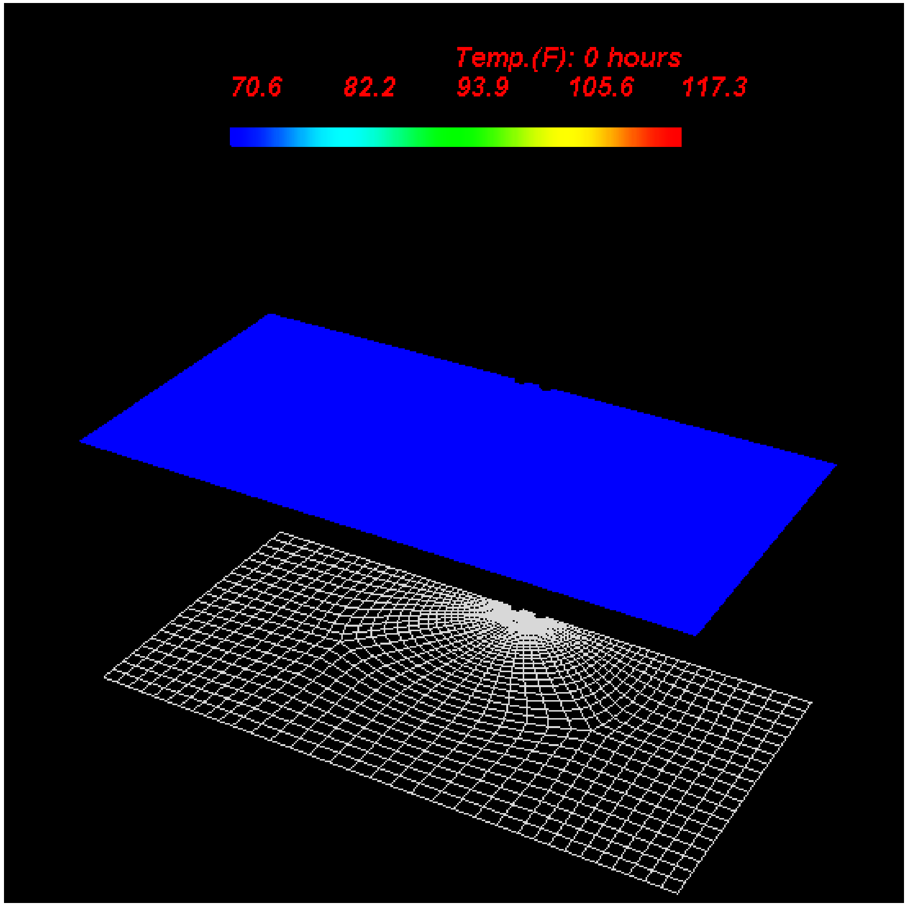


2D boundary fitted mesh of the (half) borehole

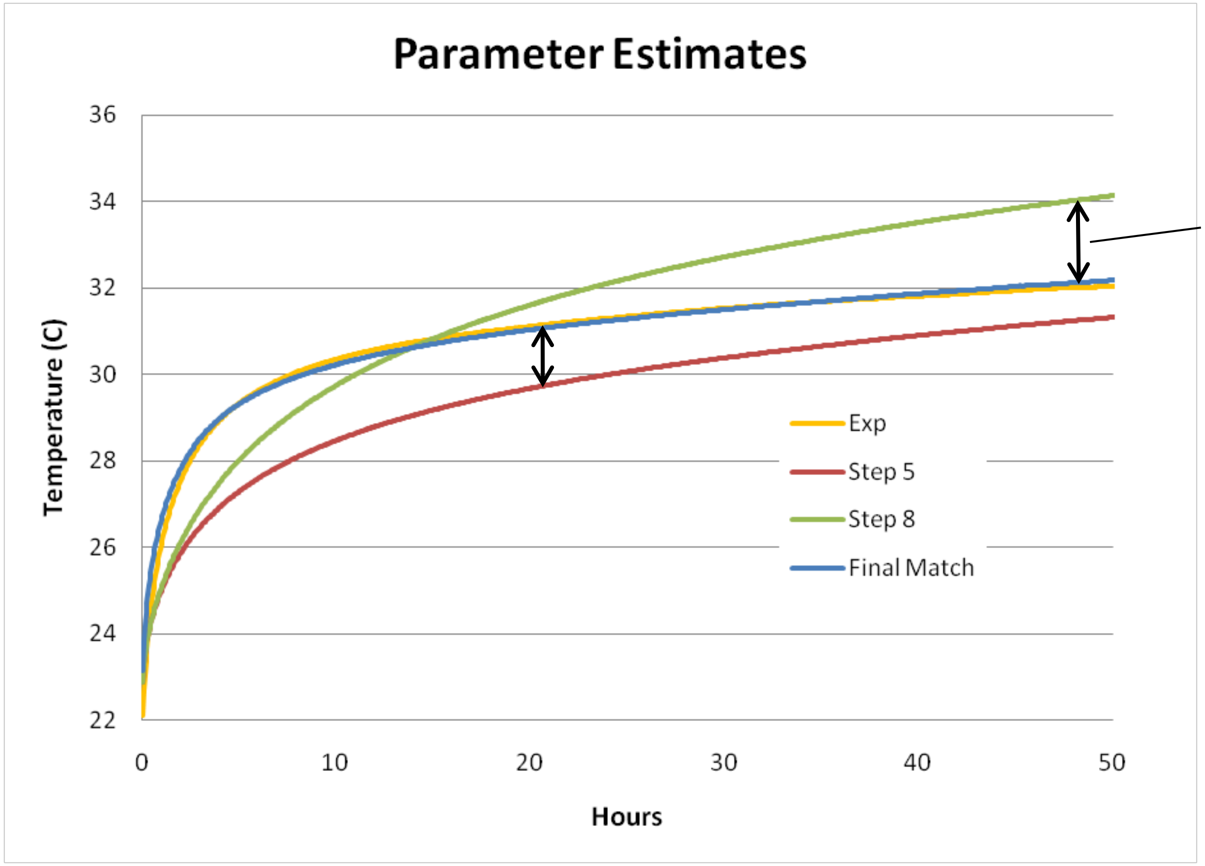


Simulated TRT temperatures

A Simulated Thermal Response Test



THE PARAMETER ESTIMATION PROCESS

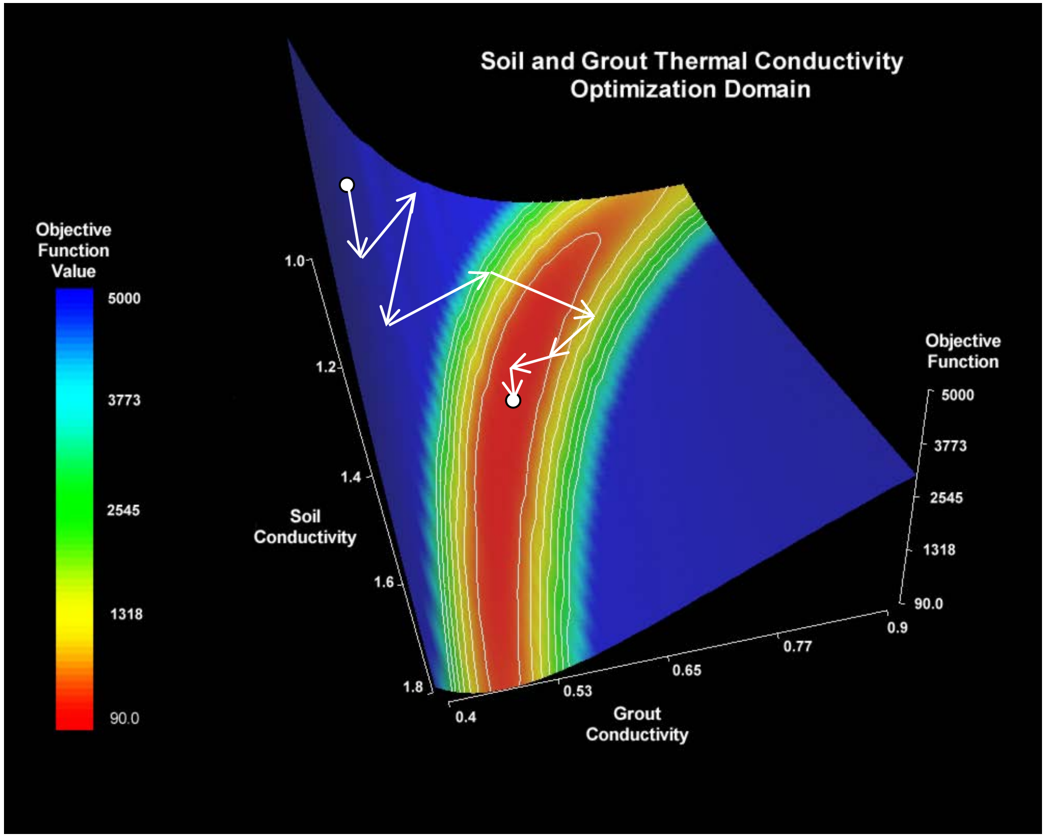


The parameter estimation algorithm automatically seeks to reduce these differences

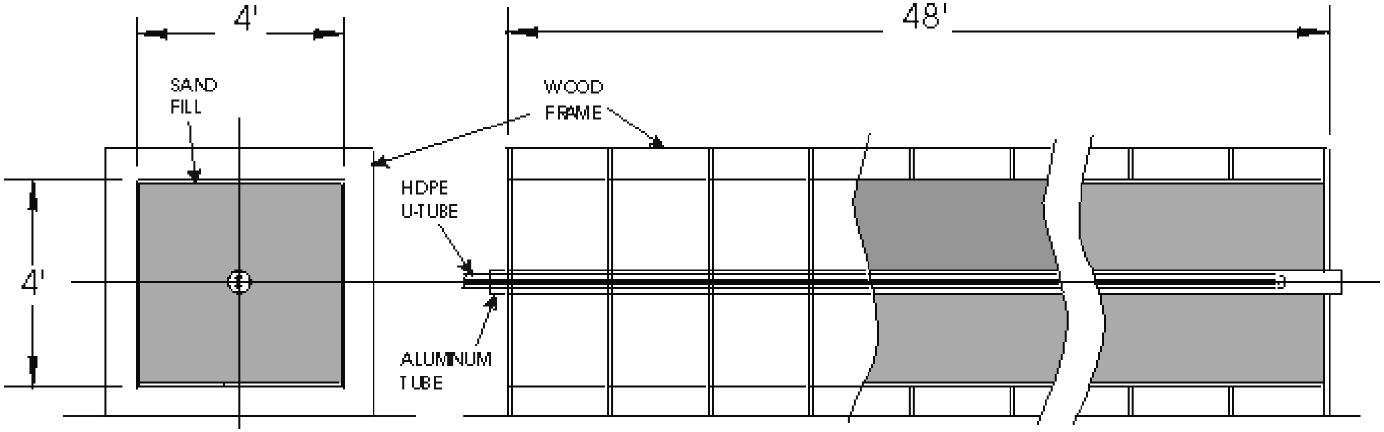
PARAMETER ESTIMATION

The parameter estimation algorithm works from an initial guess and then:

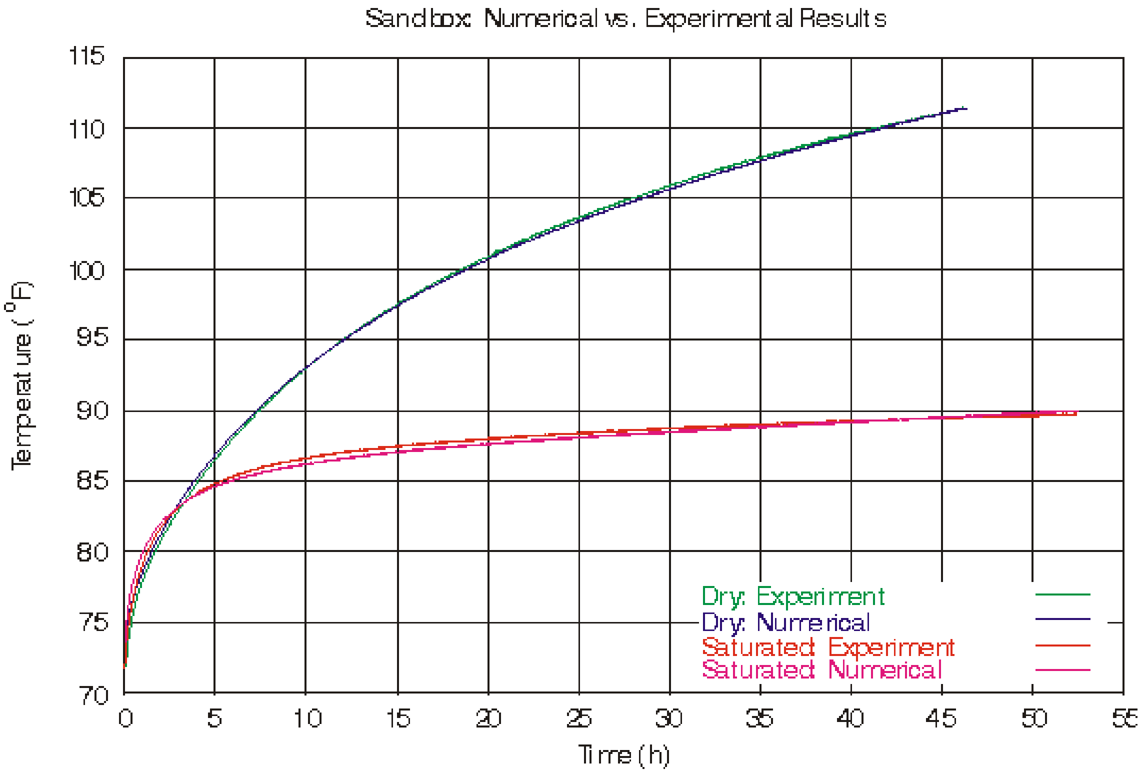
1. Runs the numerical model with the chosen conductivities
2. Calculates the differences between the numerical results and the test temperatures
3. Checks if the difference is getting bigger or smaller
4. Selects revised values of conductivity
5. Tries again until the difference is small enough



TRT VALIDATION FACILITY



VALIDATION TEST RESULTS



Temperature response matches data very well.

Estimated conductivities better than +/-10% compared to probe tests or core data.

ADVANTAGES AND LIMITATIONS

- The line-source approach:
  - Analysis is simple – can be done with a spreadsheet
  - Constant power is required – this means using a large oversized generator
- The parametric analysis approach:
  - Can deal with varying power inputs – hence generator can be small
  - Can estimate more than one parameter – both ground conductivity and borehole resistance (grout effective conductivity)
  - Specialist software is required

SUMMARY

- Research equipment developed in the 1990s has evolved into compact commercial equipment
- Research has shown:
  - Line source analysis will work if power source is very constant.
  - Parametric analysis has advantages – both in analysis and in eliminating large generators on site.
  - At least 50 hours are needed for good results
  - Estimates of +/- 10% are possible with careful testing and analysis
  - Groundwater flow is difficult to account for
- TRT provides risk reduction and more accurate costing
- Internationally recognized good practice – standards are on the way

USEFUL INFORMATION

- The IEA Annex 21 web site:

  http://thermalresponsetest.org

- The Oklahoma State University web site – many useful papers and thesis available for download

  http://www.hvac.okstate.edu

Thank You

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