Daniel Boone High School Thermal Conductivity Test

All of the borefield design programs compared in this project require the thermal properties of the soil formation at the site. Since an in situ thermal conductivity test was not performed prior to the installation of the borefield, ORNL contracted with Ted Wynne Engineering Contractors to install and grout a borehole heat exchanger at the site, and perform an in situ thermal conductivity test. The goal was to install a heat exchanger as similar as possible to the existing heat exchangers at the site, i.e. with u-tube piping of the same diameter and material, the same bore depth of 150 feet, the same bore diameter of 6 inches, and identical grout.

One immediate problem was determining the composition of the grout used in the original installation. This was identified on project records only as a "sand-concrete mix". Conversations with two of the original drillers/installers indicated that a variety of different grouts may have been used. No records of the composition of this sand-concrete mix were available, and the number of bores that included the steel casing was unknown. Accordingly, the decision was made to backfill the test well using a grout with known thermal properties. The grout selected was Grout Mix 111, a high-solids concrete-based grout developed at Brookhaven National Laboratories. The thermal conductivity of this material was reported by Brookhaven as 1.40 BTU/hr-ft-°F.

The thermal conductivity test took place on October 24, 1999. The undisturbed deep earth temperature was measured at 58.4°F. Water was heated at a rate of 4100W, and pumped through the u-tube pipes at a flow rate of 1.7 gallons per minute by a pump drawing 200W. Inlet and outlet temperatures were measured and recorded at 10 minute intervals for a period of 48 hours.

Figure 4 presents the inlet and outlet water temperatures as a function of time. Two things are noticeable: first, the temperature appears to change in steps rather than continuously, because the temperature probes were accurate to only 0.1 °F. Secondly, although the temperature begins to drop at a time of 16:40 hours, the power and flow rate are recorded as constant throughout the experiment. There are two possibilities: either there was a great deal of groundwater movement at the test site, or there were variations in power input to the water and/or variations in water flow rate that went unrecorded.

In either case, there appears to have been some problem with the test. Using the cylinder source method (Kavanaugh and Rafferty, 1996), Ted Wynne Engineering reported the thermal conductivity of the formation as 2.08 BTU/hr-ft-°F. This is a value more characteristic of dense rocks. While not impossible, it does not seem to correspond to the drilling log made during the installation of the test bore, which indicated the presence of soft limestone.

The test data was also analyzed using the Geothermal Properties Measurement (GPM) program developed at ORNL (Shonder and Beck, 2000). The program uses parameter estimation techniques and a numerical heat transfer model to determine soil formation properties. A slightly lower value for soil thermal conductivity, 1.9 BTU/hr-ft-°F, was obtained using this method, but this too seems rather high.

The results of the GPM analysis uncovered a possible explanation for the
problems with the data. Figure 5 presents the residuals from the numerical heat transfer model used internally by the program. These residuals are the difference between the predicted average water temperature (i.e., one-half the sum of the inlet and outlet temperatures) versus the measured average water temperature, using the final converged estimate for soil thermal conductivity. In a good experiment, the residuals should be uncorrelated in time, and have a mean of zero. While the graph of the residuals is centered about zero, it is clear that the residuals are correlated in time, and the error has a period of about 24 hours. The most likely explanation is that the heat input to the water loop was strongly affected by changes in ambient air temperature and/or solar radiation. For this reason, the thermal conductivity value obtained in the test probably does not represent the true thermal conductivity of the soil/rock formation at the site.

As discussed below, the initial task in the development of the calibrated simulation model was to determine the effective soil formation properties which caused the best match between the borefield model and the monitored data over a one-year period. Since the in situ test did not produce good results, it was decided to use the effective soil properties obtained from the calibrated simulation of the borefield. These were as follows:

Deep earth temperature:	59.6 °F
Soil thermal conductivity :	1.34 BTU/hr-ft-°F
Soil volumetric heat capacity:	45.7 BTU/ft3-°F

John A. Shonder
Engineering Science and Technology Division
Oak Ridge National Laboratory
P.O. Box 2008, Bldg 3147, MS-6070
Oak Ridge, TN 37831-6070
(865) 574-2015 voice
(865) 574-9329 fax

Output file from 'gpm.exe'
U.S. Department of Energy
Oak Ridge National Laboratory

Experimental data file name
C:\PROGRAM FILES\GPM\boone.dat

Output file name
boone1.out

Date: 2/15/00
Time: 2:25:38 PM

Experiment heading / comments

U-tube diameter (in)
1

Borehole diameter (in)
6.0

Borehole depth (ft)
150

Deep earth temperature (°F)
58.4

Unit selection
Btu-lb-ft-hr-°F W-kg-m-sec-°C
(*) ( )

Parameter estimation options
( ) Determine soil thermal conductivity and borehole resistance.
(*) Determine soil thermal conductivity only.

Assumed values for volumetric heat capacity
Soil volumetric heat capacity (Btu/ft^3-°F)
33.28

END OF THE INPUTS

ITERATION ESTIMATES OF PARAMETERS
ITER = Iteration number
DEEP TEMP = Deep Earth Temperature

ITER	RMS	TH. COND	DEEP TEMP
0	2.135	1.806	68.68
1	2.922	1.868	67.93
2	1.541	1.893	67.65
3	1.091	1.905	67.51
4	0.910	1.911	67.43
5	0.828	1.916	67.38
6	0.788	1.919	67.35
7	0.767	1.921	67.32
8	0.755	1.922	67.30
9	0.748	1.923	67.29
10	0.743	1.924	67.28

45.17	94.600	-0.561	0.712	-23.9
45.33	94.600	-0.576	0.712	-23.9
45.50	94.600	-0.591	0.711	-23.9
45.67	94.600	-0.606	0.711	-23.9
45.83	94.600	-0.620	0.710	-23.9
46.00	94.600	-0.635	0.710	-23.9
46.17	94.600	-0.649	0.710	-24.0
46.33	94.600	-0.664	0.710	-24.0
46.50	94.200	-1.078	0.712	-24.0
46.67	94.200	-1.093	0.713	-24.0
46.83	94.200	-1.107	0.715	-24.0
47.00	94.200	-1.121	0.717	-24.0
47.17	94.200	-1.136	0.719	-24.0
47.33	93.850	-1.500	0.723	-24.1
47.50	93.850	-1.514	0.727	-24.1
47.67	93.850	-1.528	0.732	-24.1
47.83	93.850	-1.542	0.736	-24.1
48.00	93.850	-1.556	0.740	-24.1

11 0.740 1.924 67.27

*****CONVERGED PARAMETER VALUES******

Rms	k_soil	Deep Temp.
0.740	1.9245	67.270

****

Soil thermal conductivity (Btu/hr-ft-F) = 1.9245

APPROXIMATE RECTANGULAR CONFIDENCE REGION
PARAMETERS plus and minus the below values

For k_soil	Deep T
0.2434	2.5175

NOTE: THIS CONFIDENCE REGION MAY BE A FACTOR OF TWO TOO SMALL BECAUSE 1) THE MODEL IS 1D RADIAL, NOT TREATING 3D EFFECTS CAUSED BY THE GEOMETRY AND FLUID FLOW AND 2) UNCERTAINTIES ARE IN THE FIXED INPUTS, SUCH AS IN THE HEAT FLUX.

SOIL THERMAL CONDUCTIVITY USING LINE SOURCE METHOD

Btu/hr-ft-F	F	F degrees
k_soil	Deep Temp.	Rms
2.1229	68.823	0.688

NORMAL TERMINATION OF PROGRAM