REFINEMENT AND VALIDATION OF IN SITU PARAMETER ESTIMATION MODELS.

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KEY WORDS

geothermal energy, ground coupled, heat pump, heat exchanger, in situ testing, simulation, thermal response, thermal storage, thermal conductivity.

PROJECT BACKGROUND AND STATUS

Determination of the thermal conductivity of the ground formation is a significant challenge facing designers of Ground Source Heat Pump (GSHP) systems applied in commercial, institutional as well as large residential buildings. The number of boreholes and the depth and cost of each borehole are highly dependent on the ground formation thermal properties. Hence, depending on the geographic location and the local drilling costs, the formation thermal properties strongly influence the initial cost to install a GSHP system.

The initial work to develop suitable methods to predict ground formation thermal conductivity was funded by the National Rural Electric Cooperative Association. Additional research activities were performed at the Oklahoma State University with the support of the DOE.

PROJECT OBJECTIVES

The validation of the parameter estimation method must be based on high-quality input data in order to increase the confidence in the parameter estimation model. This is to be done using a medium-scale borehole apparatus that was constructed to allow testing of in-situ parameter estimation methods under closely controlled conditions.

Shortening the computational time for the objective function evaluation and the completion of the parameter estimation algorithm is highly desirable for a fast and accurate parameter prediction. Comparison of the current parameter estimation technique is necessary to other alternative techniques to assess the suitability and efficiency of various techniques for the objective function.

Technical Objectives

- Further validate the parameter estimation procedure.
- Shorten the length of in situ tests.
- Shorten the overall analysis time by using on-line parameter estimation

Expected Outcomes

- Increase the confidence placed in the in situ tests and the parameter estimation method for predicting the thermal conductivity of the ground formation. As more comparisons that utilize high-quality data can be made available, more confidence will be placed in the prediction model.
- Decrease in the in situ testing duration. As the length of time required to complete tests is reduced, so is the cost to contractors and their clients. Reducing costs will encourage further uptake of in-situ testing in the industry and will result in higher quality and more cost effective system designs.

APPROACH

Further validation of the ground thermal conductivity parameter estimation technique has been attempted by using a medium-scale borehole apparatus and conducting a series of simulated in-situ tests. The apparatus consists of a box 4x4x48 feet with a 5" aluminum tube at its center representing the borehole. The box was filled with either dry or saturated silica sand of known thermal conductivity that represented the soil. The 'U-tube' heat exchanger pipe was inserted and grouted in the aluminum tube in the normal way and connected to the in-situ test equipment. An illustration of the apparatus is shown in Figure 1.

The main reason the two-parameter estimation procedure takes so long is that it takes time to resolve the differences between the effects of the ground thermal conductivity and the effects of the borehole resistance, or grout thermal conductivity. If a single-parameter estimation could be used, it should converge much more quickly. In order to make use of a single-parameter estimation, we would need the following:

1. Grout with known thermal conductivity.
2. Thermal characteristics of pipe well known.
3. Good estimate of the convection coefficient in the pipe.
4. Control of the U-tube placement in the hole.
5. Constant diameter borehole.
6. Highly accurate representation of the borehole geometry in the numerical model.

The first three items can reasonably be achieved. It is not at all clear whether items 4 and 5 are feasible to achieve in the field. The 6th item, the numerical model has been developed here at OSU. The numerical model used in the original work used a polar grid system that required the pipe geometry to be approximated by a 'pie sector' in the grid (see Figure 2). An improved model has now been developed that uses a 'boundary-fitted' grid system that is much more flexible and can accurately represent the U-tube pipe geometry. Details of the grid around the borehole are shown in Figure 3. This makes the calculation of the heat fluxes and temperatures inside the borehole much more accurate. This is important for prediction of the borehole response near the beginning of the in-situ test and should lead to better parameter estimations.

Both the original numerical model ant this improved numerical model have been used to estimate the soil conductivity from experimental data taken from the medium-scale borehole test facility. Estimations of the saturated sand conductivity have been made using different amounts of data up to 52.5 hours using the two-parameter method developed by Austin *et al.* and also with a one-parameter method. Estimating only one parameter assumes the grout conductivity, U-tube position and borehole size to be accurately known.

The results of these parameter estimations are shown in Figure 4 along with the results previously published by Smith for the line-source method. The results for the two-parameter method steadily increase as more data are used and approach a consistent value towards fifty hours of data. The results for the one-parameter method however, approach the independently measured value much more quickly, in a similar manner to the line-source method. It should be noted that, unlike the line-source method, the results of both the one and two-parameter methods do not rely on judgments by the user in selecting the data – the procedures are fully automatic.

It is encouraging that the one-parameter conductivity estimation method performs so well on test data of shorter duration. However, it should be emphasized that using this method requires the grout conductivity, U-tube position and borehole size to be accurately known. In practice, although the grout conductivity may be reasonably well defined, the position of the U-tube in the borehole cannot be controlled and the size of the borehole may vary along its depth depending on drilling conditions. Therefore, at present, we do not recommend its use in the field. The two-parameter conductivity estimation method we have previously recommended is able to compensate for variations in borehole size and U-tube position automatically by simultaneously estimating the *effective* grout thermal conductivity.

The parameter estimation method that has been developed previously has required two stages (1) collection of data in the field (2) off line data analysis. On-line parameter estimation would allow the data collected from the borehole to be analyzed as soon as it was available and a continually updated estimate of the ground thermal conductivity to be provided. It is also possible that feedback could be provided to the test operator and the test terminated at a shorter duration if a consistent prediction was being made. A number of methods of on-line parameter estimation have been attempted with some success using historical data (Jain 1999). These methods need further refinement and testing in the field before they can be deployed.

RESEARCH RESULTS

- Further validation experiments using a medium scale borehole apparatus showed that the parameter estimation method can be used to estimate ground thermal conductivity to a high degree of accuracy (error < 0.23%) when conditions are well controlled.

- Using a boundary fitted numerical model it was possible to arrive at reasonable estimates of the ground thermal conductivity with test data of shorter duration by estimating only one parameter. However, this approach can only be successfully used when the borehole geometry is accurately known. For this reason it does not appear that this approach can currently be used in the field to reduce test duration.
- Initial development of an on-line parameter estimation method has shown some promise of reducing the overall test and analysis time. Further refinement and field-testing of this method is still required.

FUTURE PLANS

No future plans.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Geothermal Design and Engineering, Oklahoma City, OK
Ewbank and Associates, Oklahoma City, OK

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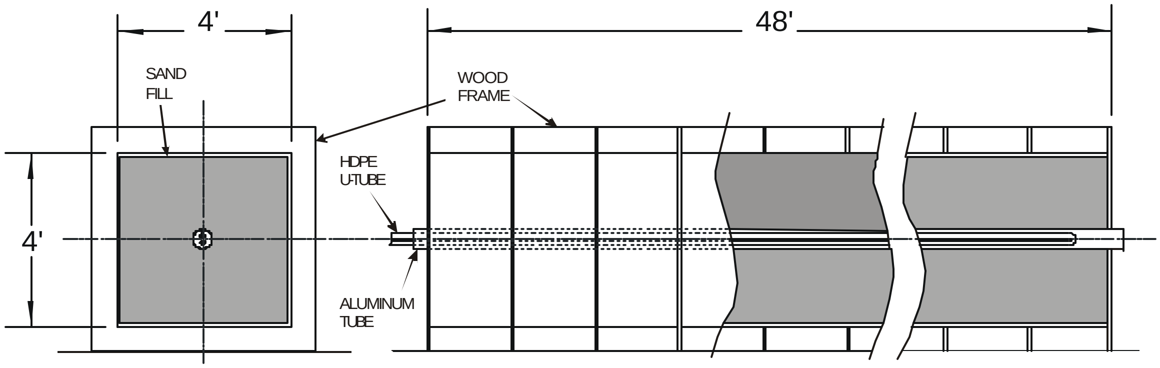

Figure 1: The medium scale borehole apparatus.

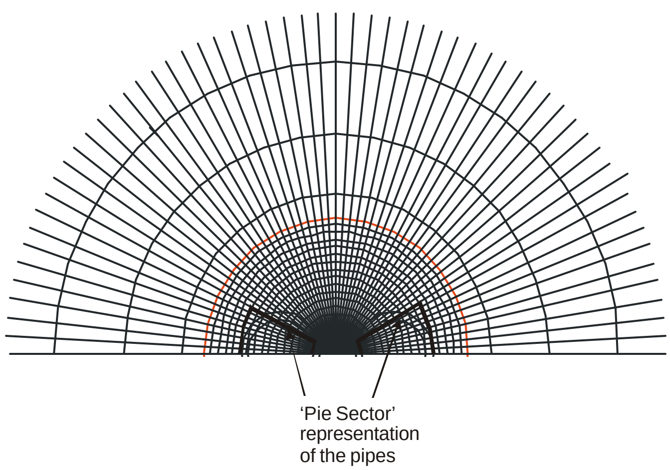

Figure 2: The numerical model polar grid with a 'pie sector' approximation of the U-tube pipe geometry.

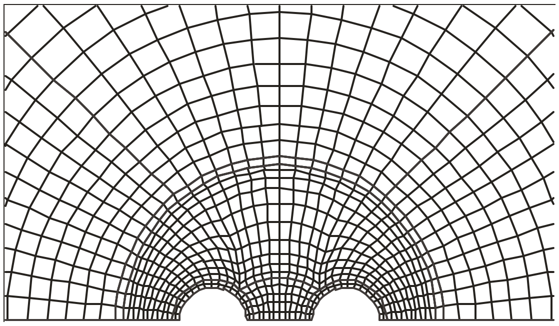

Figure 3: The numerical model boundary fitted grid showing the improved representation of the borehole and U-tube geometry.

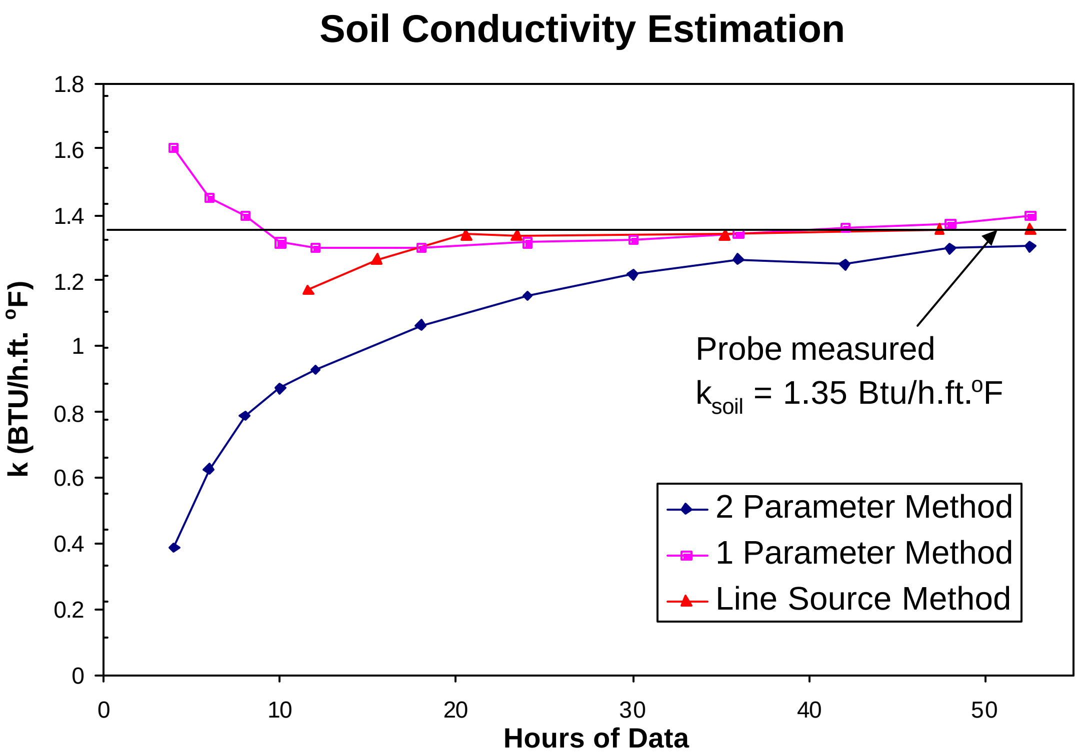

Figure 4 Results of soil thermal conductivity estimates using test data of different duration. Three sets of results are compared with the independently measured value, (a) the numerical two-parameter method (Austin 1998), (b) a one-parameter estimation method, and (c) the line-source method results (Smith 1999a).