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GEOTHERMAL HEAT PUMPS: Borehole Thermal Testing

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KEY WORDS

borehole thermal conductivity, thermal testing, formation cores, geothermal heat pumps, ground source heat pumps

PROJECT BACKGROUND AND STATUS

Geothermal heat pumps (GHP's) used in the residential and commercial heating, cooling and water heating market have demonstrated that this technology can cut costs significantly by saving energy and reducing maintenance. A reduction in first cost will encourage more applications of this technology. The development of a hardware system and associated analysis software to determine soil/rock thermal conductivity will result in more reliable designs with the accompanying strong potential to reduce first cost. Cost reduction is primarily associated with knowing a more accurate value of thermal conductivity to replace the conservative estimate which results in greater borehole depths and thus higher costs.

Ewbank and Associates privately funded the development of an in-sit thermal conductivity test trailer with technical support from OSU personnel. Their contribution to thermal conductivity measurements has resulted in a more rapid development and commercialization with this technique that would have been possible otherwise. Because of this experience, several design improvements have already been determined with regard to data acquisition, instrumentation, fluid flow system, fluid heating and heat rates, insulation requirements, power input and data interpretation techniques.

A concurrent effort, funded by NRECA, is underway to refine the accuracy of the theoretical model used to determine thermal conductivity from the measured energy input and fluid temperatures. The weighted average thermal conductivity determined from the core samples will be used to check the accuracy and validity of the refined theoretical models and also provide data to "calibrate" the model where necessary.

A parallel testing program is being conducted by Ewbank & Associates and supported by EPRI and OG&E (Oklahoma Gas and Electric) to drill and install loops and determine the thermal conductivity at approximately 30 test sites in Oklahoma which have geologic characteristics representative of locations throughout the United States. The wellbore thermal conductivity testing program would augment the NRECA project and it would work in conjunction with the EPRI/OG&E project. In-situ data from these sites will be evaluated with the calibrated theoretical model.

Direct application of this technology to field practice and use will require; 1) development of design drawings and specifications for the fabrication of in-situ testing systems, and 2) development of a training modules to be used in teaching operators how to use the system for obtaining borehole thermal conductivity values. Completion of this phase requires the completion of the refined and calibrated model.

The following has been completed or in progress: 1) cores have been extracted from two Oklahoma locations, Stillwater and Bartlesville, 2) preliminary testing has been conducted on these cores.
3) validation of the core section test method is under process 4) a set of drawings of the test trailer system has been completed using AUTOCAD software, and 5) training modules await the completion of the evaluation software.

PROJECT OBJECTIVES

Project objectives are to produce experimental data which will yield validation or calibration of refined theoretical models which evaluates in-situ wellbore data to determine thermal conductivity values for GHP wellbore field design. With the completion of the model the second objective is to assist in commercialization of the test system.

Technical Objectives

- To produce quality core data which yields accurate thermal conductivity values of core sections extracted along the extent of the wellbore from the surface to the total drilling depth. Weighted averages of these, along with in-situ test data from the same wellbore will provide the necessary information to "calibrate" a refined theoretical model.

- To produce necessary documentation and training to assist in commercialization of the thermal conductivity testing system.

Expected Outcomes

- An increase in reliable system designs with the availability of thermal test is expected to result in increased applications of GHP systems.

- A reduction in uncertainties in design is expected to reduce wellbore depth by 5 to 25 %, thus markedly reducing the drilling/loop costs in large multiple borehole fields.

APPROACH

The experimental program includes the coring of selected well sites (primarily clays, shales and consolidated rocks) to extract the materials (soils/rock) in a consolidated form which is used to determine thermal conductivity by conventional methods. The cored wellbore would be completed with a single u-bend loop and grouted, then tested with the in-situ thermal conductivity test system. The cored samples would then be tested in a laboratory to determine individual thermal conductivities. Those individual conductivities would be used to determine a weighted average thermal conductivity for the formation around the borehole.

Horizontal bores were tested with the in-situ thermal conductivity test unit and the soil adjacent to the borehole was cored vertically at discrete locations along the u-bend loop. The depth and longitudinal pipe locations in the horizontal boreholes was determined with an electronic probe developed by Charles Machine Works. The soil cores were tested with the same method as discussed in the previous paragraph.

RESEARCH RESULTS

Salient features of some research results are given in three areas, applications to horizontal bores, vertical bores and training.

In-Situ Thermal Testing Versus Cored Samples For Horizontal Bores

A 12 feet deep horizontal bore was drilled and completed with a 200 ft U-bend at Phillips University in Enid, Oklahoma. The Ewbank in-situ trailer was taken to Enid along with the portable 6 inch thermal conductivity probe to do a field test on in-situ samples of soil.

Results of the in-situ test with the Ewbank trailer on the horizontal bore was a value of 0.72 Btu/ft-hr-°F with a regression R square value of 0.966 at a time from 5.73 hours to 8.03 hours into the test. This provides an average value along the 200 ft U-bend.

The 6 inch probe was applied in the following manner. A test was done on a shallow site, digging a hole one foot deep adjacent to a cored hole. Once the hole was dug, the probe was inserted into virgin soil from depths ranging from 1 to 1.5 feet deep. The soil appeared to contain some peat and the thermal conductivity value for that location was determined to be 0.52 Btu/ft-hr-°F.

Vertical core samples in four foot sections were taken adjacent to the horizontal 200 ft U-bend path at one location and offset at other locations. Thermal conductivity values varied from about 0.45 to a maximum of about 0.77 Btu/ft-hr-°F in the interval 0 to 4 feet and from a minimum of about 0.69 to a maximum of about 0.98 Btu/ft-hr-°F in the 8 to 12 feet interval. Interpolating the curve results in a thermal conductivity value for the 1 to 1.5 feet depth of about 0.52 Btu/ft-hr-°F which is compared to 0.55 from the 6 inch in-situ probe test at Phillips University. This comparison gives confidence in the data interpretation technique.

The data from the cores were interpolated and applied to the locations along the U-bend with respect to depth and length. A weighted average value was obtained from these values which resulted in a value of 0.721 Btu/ft-hr-°F. The values obtained using the in-situ trailer value was determined to be 0.722 Btu/ft-hr-°F. Given the variations in the data for both techniques. the closeness of the result is not expected. However, the point is made that for non-grouted boreholes the current technique appears to be sufficient if the data is interpreted properly.

Electric conductivity tests were made using a device and personnel from Geoprobe Systems Inc. The test was at the location where the soil samples were obtained and tested for thermal conductivity values as reported in the previous paragraph. Electric conductivity varied from 0 at the surface to a maximum at a depth of 11 feet and then reduced to another local minimum at close to 17 feet. In contrast the thermal conductivity values initially reduced to a minimum at about 3 feet deep and then increased to a maximum somewhere between 4 and 8 feet and then reduced to a local minimum around 10 feet deep. Thus there does not appear to be a direct correlation between thermal conductivity and electric conductivity and it appears correct since some parameters influencing electric conductivity do not affect the thermal conductivity value.

In-Situ Thermal Testing Versus Cored Samples For Vertical Bores

The following discussion relates the activities which took place in coring a wellbore at Oklahoma State University. This is primarily in clay and shale formations.

Coring was done from the surface to 260 ft and the cores were placed inside 5 ft lengths of PVC sewer pipe with caps on the ends to retain the moisture. After the coring was complete a u-bend heat exchanger was grouted into the borehole which was used for determining the thermal conductivity with the in-situ test method.

Core samples from some of the aborted coring operation were used to determine the method of preparing the cores for thermal conductivity testing with a 6 inch probe. Cores kept splitting while drilling the pilot hole for the thermal conductivity probe. Thus, several drill bit types and methods of sharpening them were attempted in drilling the hole to insert the thermal conductivity probe. Drill motor speed was varied and drill bit penetration load was also changed. The distance the bit penetrated into the core before it was removed and cleaned was varied. All the initial attempts were not satisfactory since the cores continued to split. Placing an automotive ring compressor around the top of the core and one at the bottom of the core and using a good quality masonry bit allowed the insertion hole to be drilled. Once that was completed some pilot tests were begun.

Selected cores were cut in 12 inch lengths to conduct initial tests to determine the thermal conductivity of the samples. It was discovered that with the core diameter being 3 inches resulted in a more rapid influence from the core holder than expected. Because of this a guarded hot plate system is proposed to verify the values of the thermal conductivity obtained from the 6 inch probe system. Once the calibration of the evaluation method is complete then each good 1.0 foot section of core will be tested with the 6 inch probe to obtain the thermal conductivity profile.

Example Training Features

Many tests have been run with the in-situ trailer system and problem areas have arisen which need to be avoided. A couple of examples are discussed in the following material to demonstrate the type of situations for which to be aware.

Two in-situ tests were run on adjacent boreholes, one a day after the other. It was expected that the values would be similar because of the close proximity of the wellbores. During the second day of testing, a strong cold front came through Stillwater and the ambient temperature dropped. This temperature change resulted in a different slope of the time versus loop temperature curve during the test. As a result, for the corresponding time period, the first day test showed a thermal conductivity value of 1.20 Btu/hr-ft-°F and the second day was 1.47 Btu/hr-ft-°F. This clearly shows that the cold front affects the thermal conductivity values since a review of the watts versus time data shows that it remains constant and the flow rate was also essentially constant. This leaves the heat transfer from the pipes to the wellbore and from the trailer system to be the prime suspect as the source of the problem. A well insulated system is very important.

A long term test, 72 hours, revealed variations in the data starting from about 18 hours into the test, again about 42 hours into the test and also at about 66 hours into the test. A close review of the data shows that a sharp increase in watts to the heaters came first and then a sharp increase in flow rate followed with a coinciding rapid increase in temperature. In these sections the slope changed so much that unrealistic values of thermal conductivity would result, including a negative one. It is suggested that a probable cause of this is that a rapid change in air temperature and moisture content resulted in changing the rpm on the generator.

Since it was determined that a power variation caused an abrupt change in the slope of the temperature vs. time a review was made on how this could be controlled. A line voltage regulator, which will control the output to +/- 1 % is available to be purchased, but the cost is about $1900. The alternative to this is the development of software that takes into account the variations in power input which is being done in the NRECA study. One lesson to be learned is that not only the loop temperature versus time needs to be analyzed but other input parameters to the system to determine anomalies which influence the interpretation of the data.

FUTURE PLANS

Completion of a guarded hot plate system for soil/rock cores to verify the results of the probe test method is the first priority. After verification of the probe method on the cores, then completion of the core data is to take place.

A future task involves a commercial system. An initial task was to core one of four wellbores, complete it with TG85 enhanced grout, complete a drilled one with TG85 enhanced grout, another drilled one with a native bulk enhanced grout, and complete a third one with 30% Black Hills standard bentonite grout. The site in which this is taking place is in Bartlesville Oklahoma at a Phillips 66 convenience store. An in-situ test is to be run on each of the four wells. The performance will be monitored on each individual well during normal operation. This is a hard rock formation, it required hammer drilling, putting it in a different spectrum of the data than what is currently available.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

Requests about in-situ testing have come from architects and engineering firms and from companies desiring to become involved in the process as a service. Some firms have requested specifications for conducting and evaluating thermal conductivity tests. Ewbank & Associates have expanded and increased their services throughout the United States. Problems with some geothermal designs after installation has shown to be a result of short loops which could have been avoided if valid thermal conductivity values were available, thus the value of the process has been recognized.

REFERENCES

No references to the procedure are available at the present time.