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PROBLEMS ASSOCIATED WITH APPLICATION OF A WELLBORE HEAT TRANSMISSION COMPUTER CODE

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ABSTRACT

An analysis of the discrepancies between actual temperature surveys and results obtained from a wellbore heat transmission computer code are presented for recent workover operations in well EE-2 at the Fenton Hill Hot Dry Rock Geothermal site. Several sources of error in modeling the thermal behavior of wellbores are considered. These are errors in the estimation of in-situ properties, particularly thermal conductivity, the failure to include frictional heating effects when high flow rates are involved, and error in reporting the flow rate history. These errors were also found to have a cumulative effect. A sensitivity analysis of the computed results to each error type is presented for countercurrent flow. It is concluded that all the errors considered can cause temperature discrepancies between measured and computed temperature. Wellbore codes should have provisions for variable thermal properties and frictional heating. In addition, modeling efforts should be coordinated with periodic temperature surveys so cumulative errors can be minimized.

INTRODUCTION

During recent workover operation in the EE-2 wellbore at the Fenton Hill Hot Dry Rock site a wellbore heat transmission computer code (WBHT) was used to simulate downhole temperatures. Downhole temperature predictions were desired for planning of operations involving temperature limited equipment. Such operations included commercial logging for wellbore characterization, use of packers with temperature sensitive elements in fracturing attempts and the cementing of liners.

Operations over approximately a one month period, April 21 to May 15, 1982 were modeled. Figures 1 and 2 show the flow rate schedule (half hour averages) and the computed bottom hole (~15150 ft) and casing shoe (~11580 ft) temperatures. Periodic temperature logs showed a deteriorating match with time between the measured and computed values. The maximum temperature difference was about 15°C after 25 days. This caused some concern on the codes ability to model the operation and prompted the investigation of possible sources of error. Figures 3 and 4 show computed and measured wellbore temperatures for April 27 and May 3. An additional log from May 10 is used in the section on error analysis.

DESCRIPTION OF THE COMPUTER CODE

The Los Alamos wellbore heat transfer modeling code, WBHT, was designed for modeling the flow of compressed liquid in either uniaxial or countercurrent flow conditions. The equations which are solved describe the convective heat transport in the wellbore and annulus and the heat conduction in the rock matrix. These equations may be written for the wellbore:

$$\frac{\partial(\rho_w u_w)}{\partial t} + \dot{q}\,\frac{\partial(\rho_w h_w)}{\partial z} + Q_{r-w} = 0$$

and for the rock:

$$\rho_r C_r \frac{\partial T}{\partial t} + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(k\frac{\partial T}{r\partial r}\right) + Q_{w-r} = 0$$

Here T is the temperature, h is the enthalphy, k is the thermal conductivity, m is the mass flow rate, ρ is the density and w and r refer to the water and rock respectively. These equations are augmented by appropriate initial and boundary conditions. The equations are discretized using finite differences then a block iterative method is used to solve the resulting algebraic equations.

The code has been verified against published radial heat flow solutions (Carslaw and Jaeger, 1957) and very good numerical accuracy was achieved with a 400 node grid. Table 1 shows the input data used in the computer program.

SOURCES OF ERROR

In this study three sources of possible error are considered. The inaccurate reporting of wellhead data, failure to account for temperature dependent physical properties, and heating effects due to pressure drop in the pipe. These effects will be discussed and WBHT code runs with and without corrections will be compared to the temperature survey of

TABLE 1
Parameters for Wellbore Model

Parameter	Value
Rock Density (ρ_r)	2500 kg/m^3
Rock Specific Heat (C_r)	1000 J/kg°C
Radial Extent	40 m
Depth Along Wellbore	4660 m
True Vertical Depth	4396m
Nodes in r direction	10
Nodes in z direction	40
Flow rate	variable
Initial Temperature Distribution [T(°C), z - Depth along wellbore (m)]	$T = 15.3 + .093\,z$ for $z \leq 747$ m; $T = 60.7 + .0289\,z + 5.67\,(10^{-6})\,z^2$ for $z > 747$ m

May 10. The effects of spatial differencing will not be discussed.

In the complicated workover operations modeled in this study, there were several instances where inaccurate wellhead information made a significant difference in the calculated downhole temperature. In the case at hand, it was estimated that flow rates may have been as low as 80% of the previously reported values. Figure 5 shows the effect of modeling operations with a reduced flow rate. The computed results are improved a little.

The physical properties which affect the transient thermal behavior of the wellbore and rock system are the density of water and the thermal conductivitity of the rock. The effects of rock permeability and porosity are negligible because the wellbores are located in granite which has extremely small values of these properties. The importance of correctly accounting for changes in water density with temperature and pressure had been recognized from the codes' inception and an appropriate density function was obtained from steam table data. The thermal conductivity of granite varies about 25% from 40°C to 300°C (Sibbet et al, 1978). Originally the code provided for spacially dependent thermal conductivity but was later programmed to account for the temperature dependence given below:

$$K = 2.9\left(1 - \frac{T}{900}\right) \quad \frac{W}{m^{\circ}C}$$

The effect of the temperature dependent thermal conductivity on modeling is seen in Figure 6. It is disappointing that the match is poorer with the temperature dependent thermal conductivity included, though it does follow the measured flat temperature trend at the bottom of the well better than the other model.

The effects of pressure heating are usually negligible. However for circulating flow rates of 10-15 BPM though a drillpipe and wellbore can cause significant wellbore heating effects. In the original version of the computer code, the pressure heating effects were ignored; after adding the enthalpy transport terms which include the effects of pressure drop, calculated downhole temperatures during flow periods increased 20°C.

Figure 7 shows a match to the May 10th temperature log with and without the effects of frictional heating included. It is evident that the inclusion of the frictional heating produces a better match (except very near the bottom of the hole). Finally, Figure 8, shows a match of the May 10th temperature survey when the WBHT code was run including both temperature dependent thermal conductivity and frictional effects. As can be seen this improves the match and reduces the overheating effect near the bottom.

CONCLUSIONS

Errors caused in wellbore modeling by improper input data, temperature dependent thermal conductivity and frictional heating accounted for only a portion of the differences observed between temperature surveys and computed values. Other sources of errors could include the presence of fractures around the wellbore which would negate the assumption of radial flow. Overall, however, the WBHT code proves to be a useful tool, predicting temperature within ± 12°C. This could be improved by using the periodic temperature surveys to update input data and minimize cumulative effects.

REFERENCES

Carslaw, H.S. and Jaeger, J.C. (1957), Conduction of Heat in Solids, Oxford University Press, pp. 342-344.

Sibbet, J.G., Dodson, J.G. and Tester, J.W. (1978), "Thermal Conductivity of Rocks Associated with Energy Extraction from Hot Dry Rock Geothermal Systems", Thermal Conductivity, v. 15, pp 399-421.

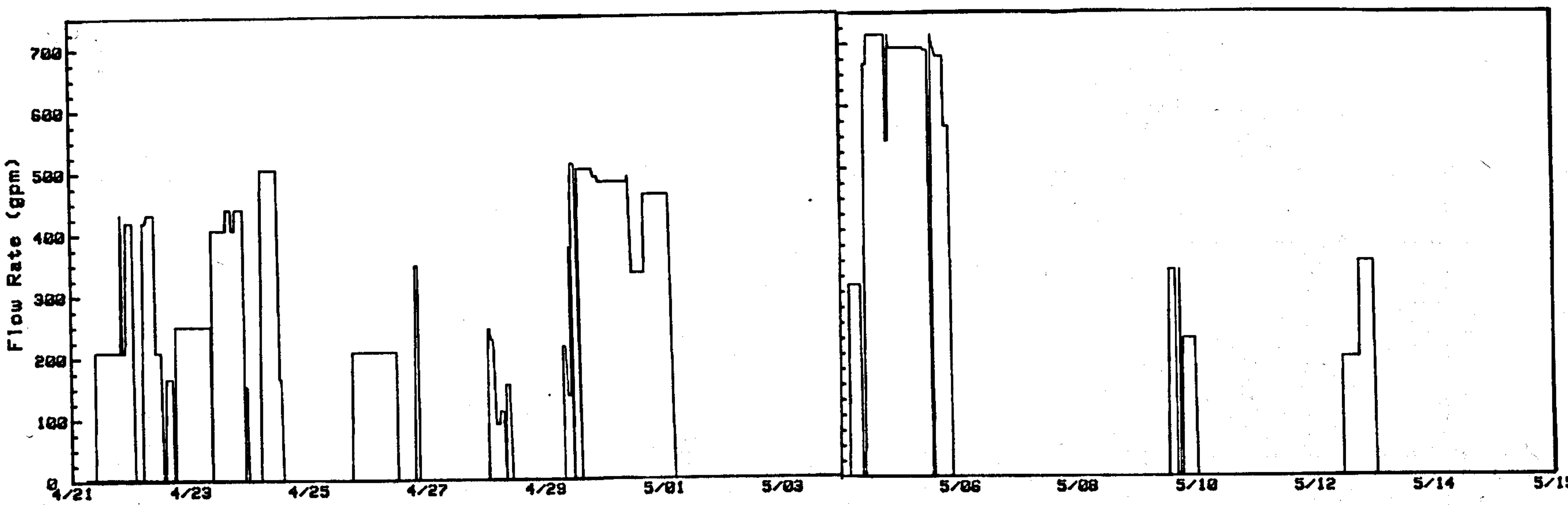

Figure 1. Flow rate history for April 21 through May 15, 1982.

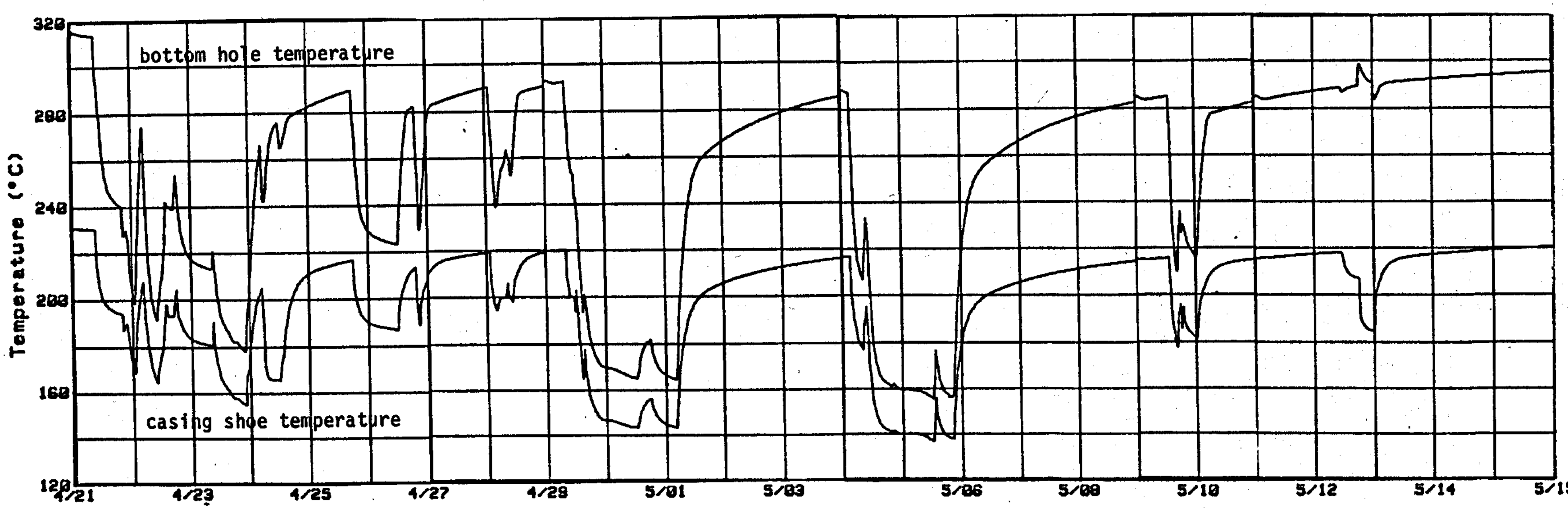

Figure 2. Computed bottom hole and casing shoe temperatures for April 21 through May 15, 1982.

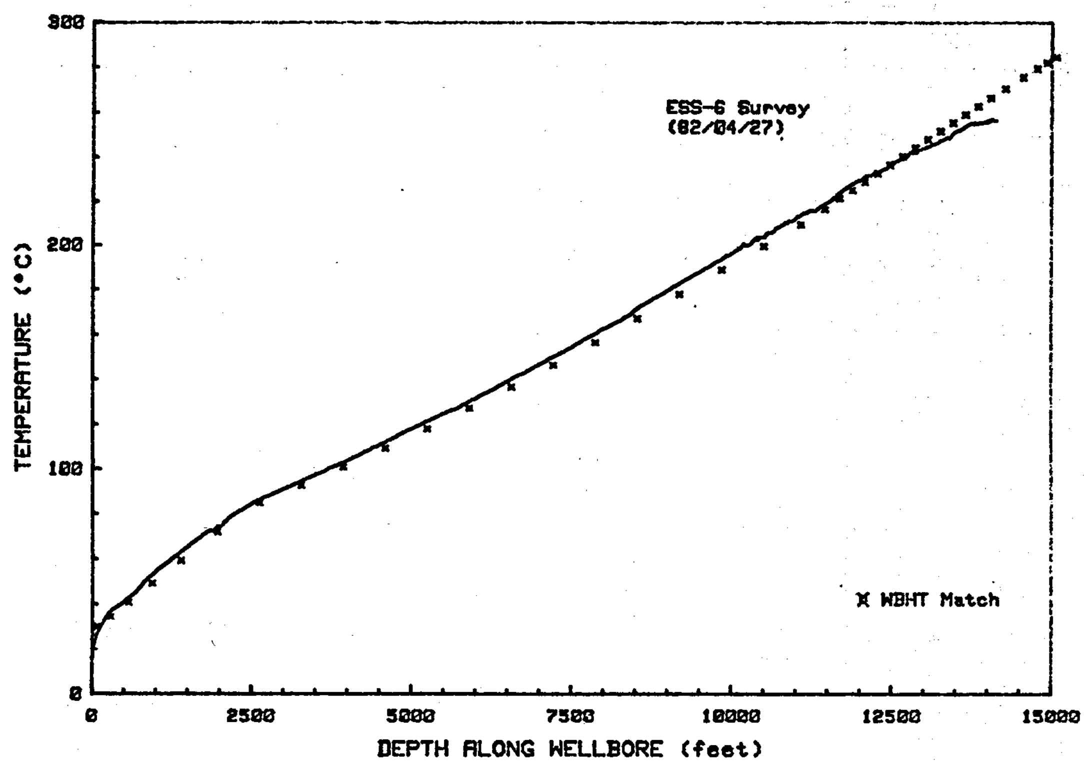

Figure 3. Temperature Survey in EE-2 wellbore, April 27, 1982, with WBHT code match.

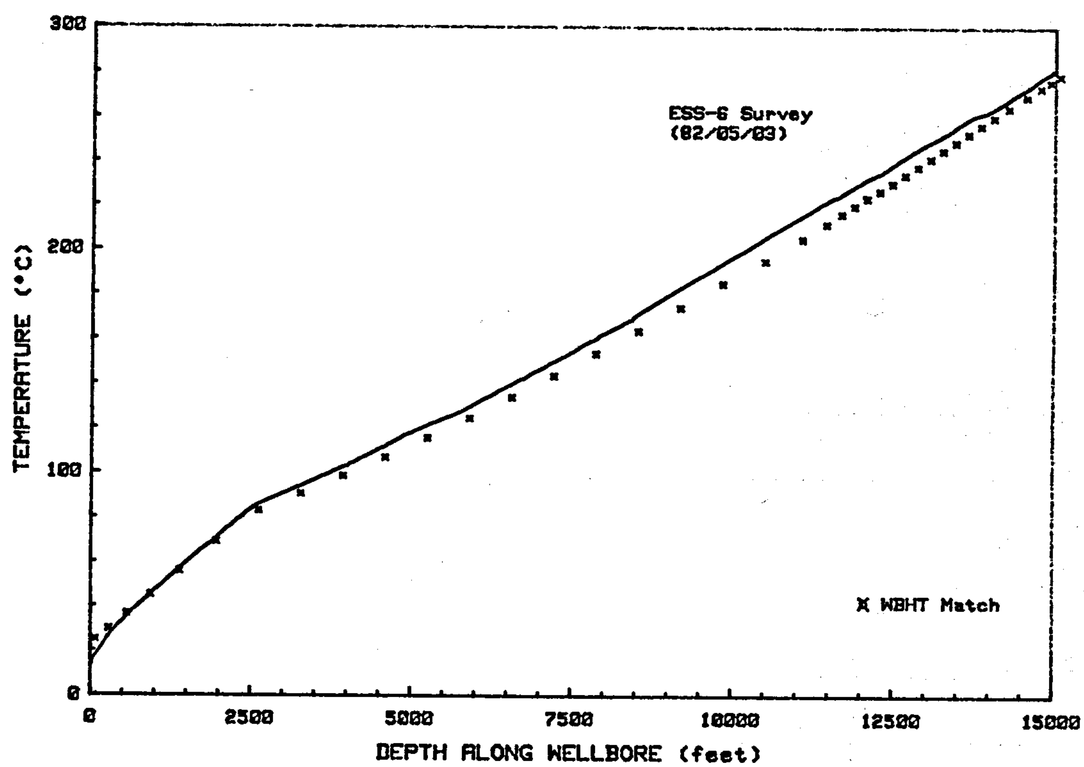

Figure 4. Temperature Survey in EE-2 wellbore, May 3, 1982, with WBHT code match.

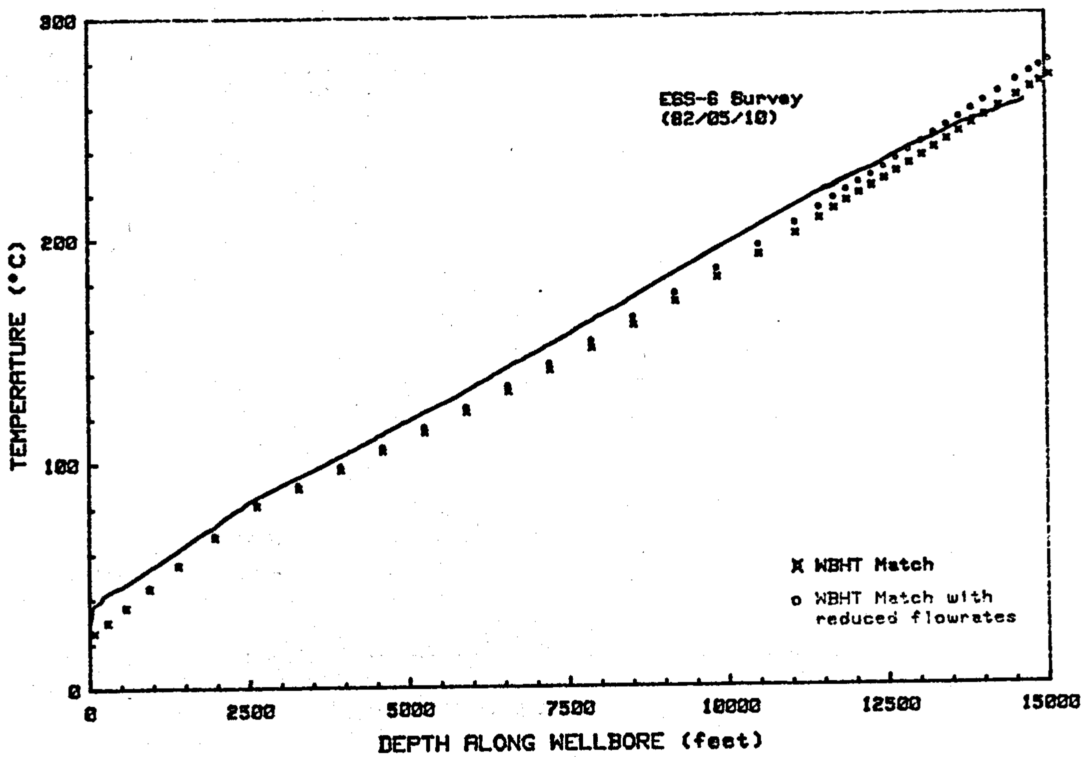

Figure 5. May 10, 1982 Temperature survey in EE-2 with WBHT code matches with and without reduced flow rates.

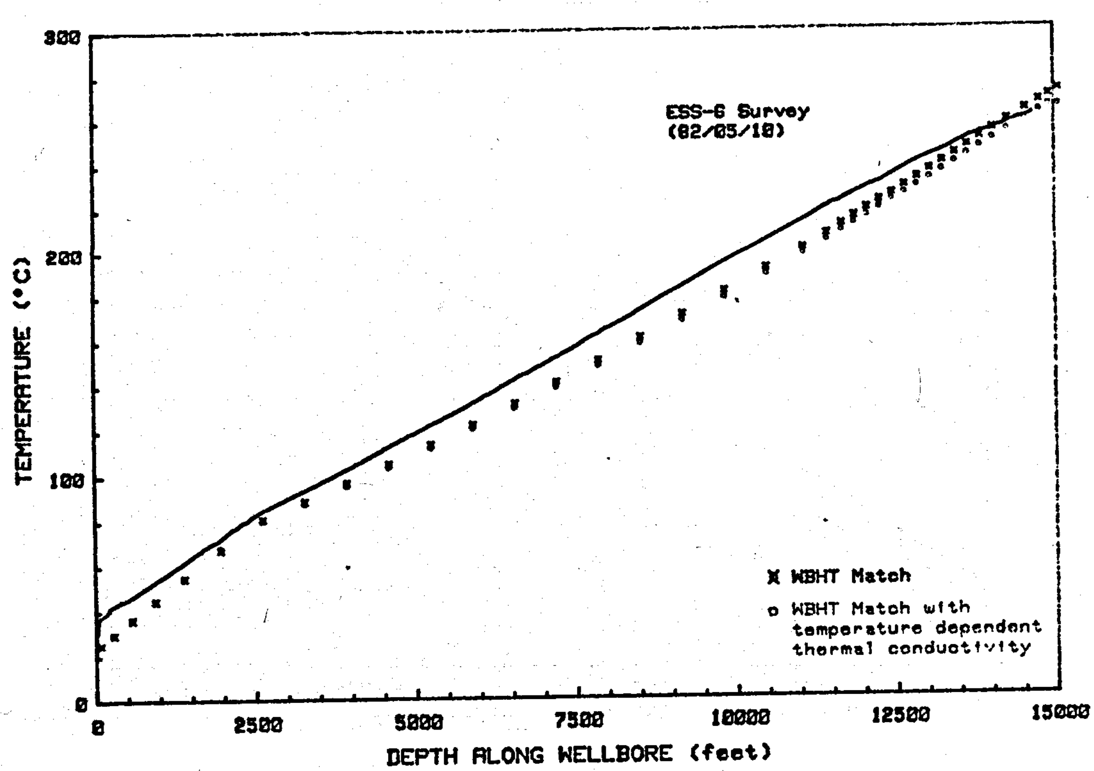

Figure 6. May 10, 1982 Temperature survey in EE-2 with WBHT code matches with and without temperature dependent thermal conductivities.

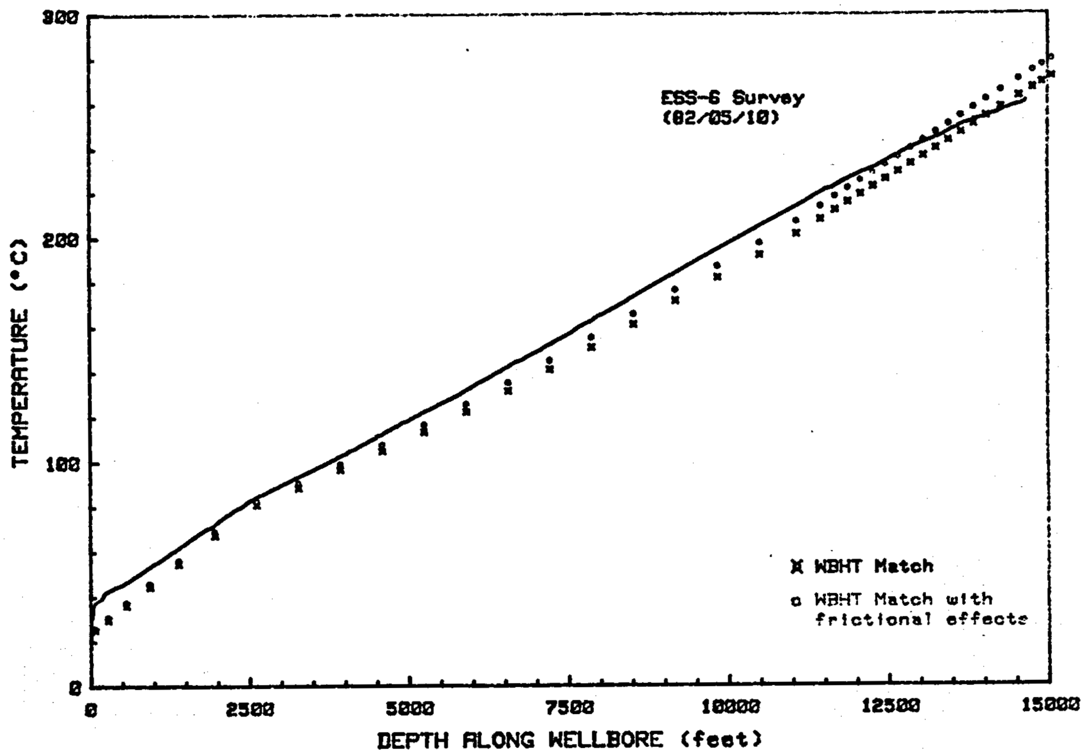

Figure 7. May 10, 1982 Temperature survey in EE-2 with WBHT code matches with and without frictional heating effects.

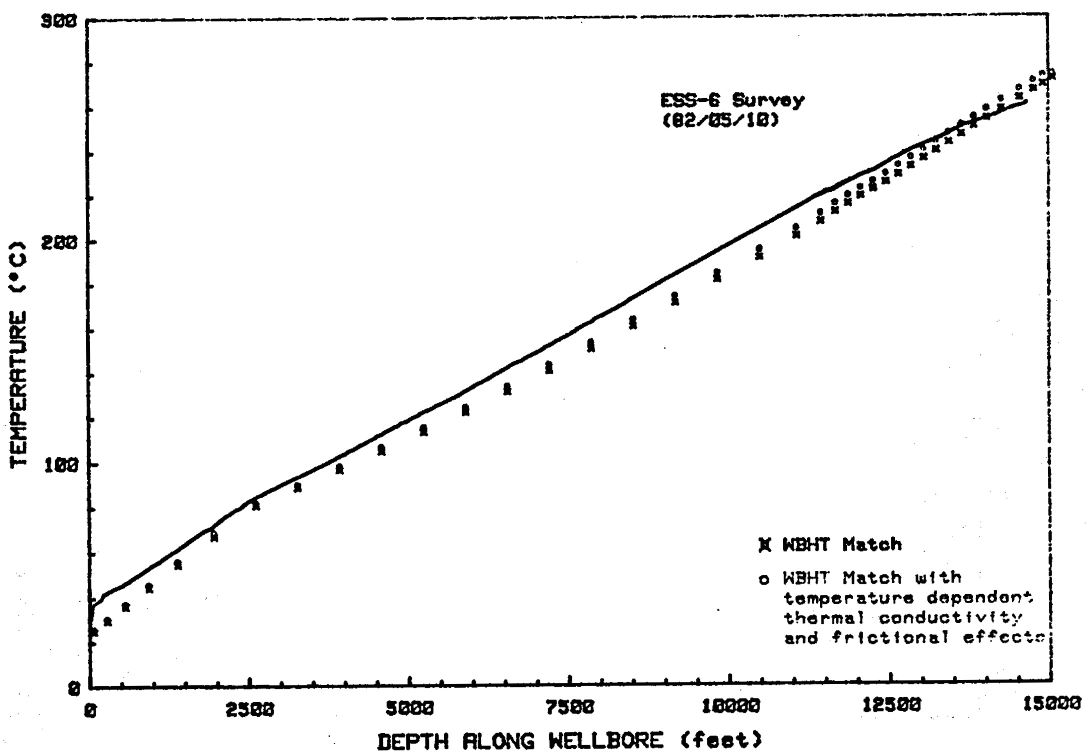

Figure 8. Temperature survey of May 10, 1982 in EE-2 with WBHT match including temperature dependent thermal conductivity and pressure heating effects.