STEADY-STATE AND TRANSIENT WELLBORE TEMPERATURES DURING DRILLING

"DEVELOPMENT OF AN IMPROVED GEOTHERMAL DRILL BIT"

TTI CONTRACT E (10-1) - 1546

TASK 1: ANALYSIS OF HEAT FLOW

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STEADY-STATE AND TRANSIENT WELLBORE TEMPERATURES DURING DRILLING

SUMMARY

An extensive literature search was made to locate technical publications and computer programs relating to wellbore temperatures during drilling operations. Publications obtained are listed in the References. Examples in these publications confirmed the need for knowledge of transient and steady state circulating temperatures in the design of geothermal bits.

Two approaches were used in calculating borehole temperatures: The steady state solution of Holmes & Swift was programmed and 2100 cases calculated for various borehole configurations. For transient temperature studies, Exxon Production Research Co. made calculations for ten borehole configurations under a \$5,000 subcontract. These calculations help emphasize the need for better high temperature bit performance and improved engineering procedures in drilling.

The conclusions and recommendations discussed in the following sections are based on latest available technology for calculating wellbore temperatures. Until geothermal wells and hot oil and gas wells became more common this type of information was rarely needed. Now that need does exist and the technology must be developed to fill it.

CONCLUSIONS

Based on search and review of publications on borehole temperatures, we conclude:

1. Surface mud cooling systems will be required for hot geothermal well:
 - a. to protect surface equipment.
 - b. to protect bits, seals, and lubricants.
 - c. to maintain mud performance.
 - d. for corrosion protection.
2. Improved engineering procedures could extend the life of downhole equipment.
3. There is an important need for improved technology for calculating borehole temperatures:
 - a. Differences of 40°F or more between measured and calculated temperatures have not been satisfactorily resolved.
 - b. There have been no attempts to develop and calibrate thermal models for high bottom hole temperatures.
 - c. There is no transient wellbore temperature model publicly available.
 - d. Extensive numerical studies are needed to help understand and predict steady-state and transient wellbore temperatures.
4. There have been no attempts to simulate temperatures within the bit.

RECOMMENDATIONS

Based on our studies and its conclusions, we recommend the following:

1. Engineering procedures and protective equipment should be developed and implemented for protecting the bit from high wellbore temperatures during tripping and other pump shut-downs.
2. A general purpose, circulating borehole thermal simulator such as that of Sullivan should be further developed and calibrated. Such a model should be made available for public use.
3. Comparisons should be made of measured and computed borehole temperatures for geothermal wells.
4. Comprehensive studies should be made of parameters affecting borehole temperatures in geothermal wells.
5. The feasibility of developing and calibrating a thermal model of the drill bit should be studied.

STEADY-STATE AND TRANSIENT
WELLBORE TEMPERATURES DURING DRILLING

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INTRODUCTION

The design of bits for drilling in very hot geothermal environments and the prediction and control of downhole drilling fluid properties depends on knowing circulating temperatures in the wellbore. A limited number of publications pertinent to calculating borehole temperatures were located; they are listed in the attached references. The physical phenomenon of why and how borehole temperatures are different from rock temperatures is discussed in the following paragraphs.

The drilling fluid becomes a heat transfer material in a counter-current heat exchanger formed by the drill pipe and the borehole. This circulating system is shown schematically in Figure 1.

Figure 1. Schematic of Circulating Fluid System (Raymond, 1969)

This circulating system has three distinct parts: 1) fluid enters the drill pipe at the surface and passes down through the drill pipe; 2) fluid exits the pipe through the bit nozzles cooling the bit and cleaning the cutters and entering the annulus at the bottom; 3) fluid returns up the annulus and exits the annulus at the surface. An accurate simulation of the thermal behavior of the fluid in this system must treat all three parts of the circulation including heat gain from the formation, transfer of heat between inside and outside of the drill pipe and heat generated by the bit.

In part one, the fluid enters the drill pipe at a known temperature and flow rate. As the drilling fluid flows down the pipe, temperature is determined by the rate of flow (forced convection) down the pipe, the rate of heat exchange between the drill pipe and the annulus, and the length of the drill pipe. Heat gain due to friction should be added; this is very difficult to estimate, however.

In part two the drilling fluid exits the bit and enters the annulus. Heat generated by the bit is added to the fluid at this point. Also at this point the boundary condition is imposed that the temperature is the same inside and outside of the drill pipe. In part three the fluid flows up the annulus. Its temperature is determined by the flow rate (forced convection) up the annulus, the rate of heat exchange between the adjacent formation and the fluid in the annulus, and heat exchanged with fluid within the pipe. Of course, time (or length of exposure) affects total heat transferred.

In order to properly account for the heat exchange between the formation and fluid in the annulus, a numerical model should include the capability of accounting for the effects of additional casing strings and cement or fluid behind the casing.

Geometry for such a model is shown in Figure 2.

Figure 2. Geometry for Wellbore Temperature Model
(Keller et al, 1973)

The boundary conditions for temperature calculations are usually 1) mud inlet temperature and circulation rate are known; 2) the inlet and outlet flow rate are the same; 3) the initial distribution of fluid temperature in the drill pipe and annulus is given by the geothermal gradient; 4) the formation is an infinite heat sink; 5) heat flow in the formation is radial.

When circulation begins, temperatures along the length of the borehole change very rapidly. The bottom hole

temperature becomes considerably cooler and temperatures near the surface become somewhat warmer than at equilibrium. Figure 3 shows this time dependence of bottom hole and outlet temperatures for 20,000 feet well. As may be seen from the figure, the initial temperature of the formation is 400°F at the bottom but, under equilibrium circulating condition, the bottom hole wellbore fluid temperature is about 260°.

Figure 3. Time Dependence of Temperature After Initiating Circulation for a Simulated Well (Raymond, 1969)

Figure 4, which shows circulation being initiated and then stopped after 16 hours and the time dependence of borehole temperatures during these periods, illustrates two very important elements in the design of an improved geothermal bit. First, by adequately cooling the hole, including breaking circulation as the bit is run into the hole, it may not be necessary to design geothermal bits to take the maximum temperatures of formations penetrated by the bit. Second,

Figure 4. Temperatures In A Simulated Well For Starting and Stopping Circulation (Raymond, 1969)

there is a time dependence such that if circulation is not maintained while the bit is in the hole (for example, there is a pump failure) then there is some period of time to reestablish circulation before damage will occur to the bit.

Figure 5 illustrates annulus temperatures for a simulated well. Note that the formation between the surface and about 10,000 ft. is being heated and the formation below this is being cooled. Maximum fluid temperature occurs at 17,000 ft. This point will tend to move up the hole as circulation time increases. Raymond's studies indicated that the maximum temperature usually stabilized about one-fourth to one-third of the way up the annulus from the bottom of the hole. Of course, location of the maximum temperature point is dependent on parameters such as circulating velocity, mud weight, etc. For this simulated well, the time to approach steady state was

approximately 16 hours. This seems to be true for both cases tripping into and tripping out of the hole.

Figure 5. Annulus Temperature vs. Depth As A Function Of Time For A Simulated Well (Raymond, 1969)

In tripping out of the hole there is no forced convection during the trip. Therefore, the important modes of heat transfer are heat exchange with the formation and conduction in the fluid. In general conduction in the fluid was found to be negligible and the temperature during the trip was found to be adequately approximated by heat exchange with the formation assuming that the fluid temperature is equal to the formation temperature at the borehole wall.

It should be recognized that drilling fluid properties will be strongly influenced by temperatures to which the fluid is exposed. Figure 6 shows a plot of the percent of fluid above a given temperature versus temperature. For geothermal systems this type of calculation may become important in assessing degradation of borehole fluids.

Figure 6. Percent of Fluid Above a Given Temperature
(Raymond, 1969)

The validity of calculations such as those by Raymond (1969) and by Keller, Couch and Berry (1973) has been questioned by Sump and Williams (1973). In their study, Sump and Williams were able to use field data to determine heat transfer coefficients by regression analysis. Comparing results with these heat transfer coefficients with those used by others led to differences in bottom hole temperatures as great as 60°F. In comparison, outlet mud temperature did not prove to be sufficient test of correct bottom hole temperature calculation.

The results of Sump and Williams indicate that while a good borehole circulating temperature model will be extremely useful in the design of geothermal bits, the calculation will be very sensitive to input parameters and to assumptions such as the linearity of the geothermal gradient. Their work also demonstrates that there will be a need to obtain field measurements of circulating temperatures in order to calibrate the model if it is to be used on a continuing basis in the design of bits and in the design of proper operating procedures for geothermal drilling.

COMPUTER MODELS

It was apparent from our studies that numerical modeling of temperatures in geothermal wells would be useful in developing an improved geothermal bit and in planning testing of the bit. The Holmes and Swift model for calculation steady-state borehole temperatures was programmed and parametric studies made based on runs of 2100 cases. These are discussed in the following section.

Several organizations believed to have computer models for calculating transient borehole temperatures were contracted to try to obtain a model for use in design of an improved geothermal bit. These organizations were Exxon, Sun Oil, Halliburton, and Mobil. In addition, Control Data Corporation and University Computing were contacted about the use of network simulators or contracting with them to develop a borehole temperature model. CDC submitted a proposal to adapt the MIDAS structural analysis package to this problem. The proposal was not acceptable because of the awkwardness to adapt a network analyzer to the circulating fluid problems, because the expense of using this powerful model would prohibit detailed parametric studies and because of the cost of their proposal.

Exxon Production Research Company (EPRC) responded with quote to run ten specific cases using their CIRCUS program (which is based on the Raymond model) for \$5,000. This proposal was accepted. The cases studied are discussed following discussion of studies based on the Holmes and Swift steady-state model. Descriptive information on the CIRCUS program is presented in the Attachments.

After work with EPR was underway, Sullivan of Sandia Laboratories published a report, "A Wellbore Thermal Model," based on a finite difference approach. From the report, it appears that his approach has potential for use in further transient wellbore temperature studies.

CALCULATION OF STEADY-STATE TEMPERATURES

The analytic model of Holmes and Swift was programmed and used to calculate steady-state circulating temperatures for 2100 cases of interest in geothermal drilling. Holmes and Swift present an excellent discussion of the model in their 1970 publication. The cases studied are presented in Table I.

The results of these calculations are summarized in Figures 7-9. These figures, which are basically self-explanatory, demonstrate the dependence of the bottom hole, steady-state circulating temperature on factors such as bottom hole formation temperature, mud weight, total depth, inlet temperature and mud flow rate.

As seen from Figure 7, the bottom hole steady-state circulating temperature increases with well depth and depends linearly on formation temperature. Figure 8 illustrates the lower heat capacity of lighter muds for the same conditions as in Figure 7. In most geothermal situations, lower mud weights will be required. The need for adequate mud cooling equipment on the surface is illustrated by Figure 9 which shows the bottom hole temperature dependence on mud inlet temperature. The importance of this cannot be overstressed since the performance of the drilling fluid and the life of the bit and other downhole hardware may be dependent on thermal history and cumulative time at temperatures above a given level.

Results of the Holmes and Swift model studies were compared with the limited data from calculations using the CIRCUS program (discussed in the next section). Differences of 40°F in bottom hole steady-state circulating temperatures were noted. The reason for these important differences is ascribed to differences in the mathematical approach as well as differences in heat transfer coefficients. Proper values cannot be ascertained since there are few data to calibrate these programs.

Table 1

CASES STUDIED

Dia (Pipe)	=	4.5"		
Dia (Hole)	=	8.625		
C _p (Mud)	=	0.9		
C _h (Pipe)	=	30		
C _h (Ann)	=	1		
T (Surf)	=	80°F		
T (Inlet)	=	100°F	Flow Rate	= 200 gpm
		125		400
		150		600
		175		
		200		
BHT	=	400°F		
		500		
		600		
		700		
		800		
TD	=	6,000 ft.		
		10,000		
		14,000		
		18,000		
		22,000		
		26,000		
		30,000		
Mud Weight	=	10 #/gal		
		12		
		14		
		16		

$$\begin{aligned}
 \text{Number of Cases} &= T(\text{In}) \times \text{BHT} \times \text{TD} \times \text{Weight} \times \text{Flow Rate} \\
 &= 5 \times 5 \times 7 \times 4 \times 3 \\
 &= 2100
 \end{aligned}$$

FIGURE 7

STEADY STATE CIRCULATING TEMPERATURE AT BOTTOM (°F)

CIRCULATING TEMPERATURE AS A FUNCTION OF
FORMATION BHT FOR DIFFERENT MUD WEIGHTS

DEPTH = 10,000 FT
FLOW RATE = 200 GPM

FIGURE 8

CIRCULATING TEMPERATURE AS A FUNCTION OF
FORMATION BHT FOR DIFFERENT INLET TEMPERATURES

DEPTH = 10,000 FT
MUD WT = 10#/GAL
FLOW RATE = 200 GPM

FIGURE 9

TRANSIENT TEMPERATURE ANALYSES

Circulating drilling fluid both removes and redistributes heat in the borehole. When circulation is initiated, as after tripping, the temperatures in the borehole will change from being the same as the geothermal gradient to some new steady state condition. Similarly, if circulation is stopped, the borehole temperature distribution will return slowly to equilibrium with the formations around it.

Temperatures in the borehole during this non steady-state or transient period are important because of possible detrimental effects on downhole equipment such as bits and on drilling fluids. For example, how long could a bit remain on bottom, without damaging seals or other temperature sensitive parts, if circulation were stopped?

Calculations of transient temperature behavior are discussed in the literature (see Table 2), but no analytic or numerical models are readily available for performing such calculations. Since this project afforded neither the time nor funds for development of such, inquiries were made for access to suitable model to four separate organizations. These were Mobil Research and Development Corporation, and G.E. Computer Systems. Bids from the two computer companies were not cost effective; Mobil declined to make their program available. EPRC responded with a quote to run ten cases with their CIRCUS program for \$5,000 (see attachments). This proposal was accepted and the work performed.

Table 2
PUBLISHED STUDIES

Ramey	1962	
Raymond	1969	Transient (Neglects Casing and Internal Heat Sources)
Holmes and Swift	1969	Steady State Only
Keller, Couch & Berry	1973	Transient, Neglects Internal Sources
Sump and Williams	1973	Compares and Calibrates Raymond Model To Field Data
Lea	1975	Network Analysis
Sullivan (Sandia)	1976	Finite Element Model

The ten transient temperature cases computed by EPRC under subcontract on this project were selected to be representative of a variety of geothermal conditions. These are listed in Table 3 along with some of the basic mud temperatures. Typical results are presented in Figures 10-15.

Figure 10 shows typical circulating temperatures for Case 1. Note that when circulation is initiated ($t = 0$), the temperature at the bottom of the hole drops rapidly from 500°F to about 160°F. When the well is shut in after five (5) hours, the temperature rises rapidly, but still remains cooler than the formation temperature for the duration of the calculation (17 hours).

Figure 11 is a cross-plot of results of different cases to show the effect of geothermal gradient on the bottom hole circulating temperature. As may be seen from this figure,

TABLE 3
GEOHERMAL BOREHOLE TEMPERATURE CALCULATIONS
EXXON 'CIRCUS' PROGRAM

CASE	DEPTH (FT)	STATIC BOTTOM HOLE TEMPERATURE (°F)	CIRCULATION RATE (GPM)	GEOHERMAL GRADIENT (°F/100 FT)	CIRCULATING BOTTOM HOLE TEMPERATURE (°F)	INLET TEMP. (°F)	OUTLET TEMP. (°F)
1	5,000	500	200	8.4	154	135	157
2	5,000	500	400	8.4	154	135	151
3	10,000	500	200	4.2	258	135	178
4	10,000	500	400	4.2	255	135	167
5	5,000	750	200	13.4	169	135	176
6	5,000	750	400	13.4	169	135	164
7	10,000	750	200	6.7	348	135	214
8	10,000	750	400	6.7	344	135	195
9	5,000	500	400	8.4	144	135	163
10	10,000	500	400	4.2	213	135	151

RUN CONDITIONS:

HOLE DIA. (IN.) : 8.625 (CASES 1-8)
: 12.5 (CASES 9,10)
DRILL PIPE DIA. (IN.) : 4.5
MUD WT. (PPG) : 9.0
MUD VISCOSITY (CP) : 30.
SURFACE TEMP. (°F) : 80.

FIGURE 10

FIGURE 11

the bottom hole circulating temperature in a 10,000 ft. well increases fairly rapidly with an increase in geothermal gradient (i.e., an increase in the formation temperature at the bottom of the hole). A 5,000 ft. deep well is seen to be less sensitive to geothermal gradient. This illustrates the importance of heat exchange between mud flowing up the annulus and mud flowing down the drillpipe. For the cases studied, a two-fold change in flow rate from 200 to 400 GPM did not greatly affect bottom hole circulating temperatures. This somewhat unexpected result is believed to be a consequence of differing heat transfer coefficients generated within the program as well as the high temperatures which were the objectives of this study.

Temperature profiles after five hours of circulation are shown in Figure 12 for a 5,000 ft. case. Temperatures are seen to have changed dramatically from the assumed linear geothermal gradient to temperatures which vary only slightly with depth. This figure illustrates several points about circulating borehole temperatures: 1) the annulus temperatures exceed the drillpipe temperatures; 2) at the bit, annulus and drillpipe temperatures are equal (this is a boundary condition); 3) the maximum temperatures do not occur at the bottom--this is about mid-depth for the annulus and three-quarter depth for mud inside the drillpipe.

Changes in circulating temperature profiles with time are shown more clearly by Figure 13. This figure, based on the case of a 10,000 ft. well with 750° bottom hole formation temperature (BHT) illustrates that the borehole has been cooled significantly with 1 hour of circulation and much cooler yet after 5 hours of circulation. For this case, equilibrium

TEMPERATURE PROFILES
AFTER FIVE HOURS CIRCULATION
AT 200 GPM, 9.0 PPG MUD (CASE 1)

FIGURE 12

FIGURE 13

was fairly well established 5 hours after circulation was begun. Total time to circulate mud around in this case was 100 minutes.

Borehole size affects circulating temperatures as illustrated by Figure 14. The larger diameter will hold more drilling fluid and is able to remove more heat from the bottom of the hole.

Inaccuracies

The discussion of transient temperature calculations thus far has emphasized general observations and conclusions. It should be noted that important differences in calculated temperatures are obtained between programs. In the case of the Exxon program used for our calculations, large differences in calculated temperatures were observed when calculations were made under the same conditions and compared with calculations published by Raymond (1969). These comparisons are shown in Figure 15. Sump and Williams (1973) had published data showing differences of up to 60°F between field measurements and calculations under the same conditions.

Source of these differences could be attributed to many causes. But the important point is that uncertainties between measured and predicted temperatures can be large, and for hot geothermal wells could be unacceptably high. Much work remains to be done to understand heat transfer in the drilling fluid and the rock related to the borehole system. Both steady-state and transient field data must be taken and compared with computational results.

FIGURE 14

FIGURE 15

A good, general purpose, transient temperature wellbore model is needed for these studies. Recent work by Sullivan at Sandia Laboratories has good potential for becoming such a model.

It should be observed that all calculated temperatures were for the circulating drilling fluid system. There have been no attempts to develop or use models to determine temperatures within the bit. Maximum reading temperature probes and metallurgical analysis indicates that bits used in the Geyser's field reached temperatures on the order of 800-1000°F before removal. Measurements of temperatures of test bits manufactured for the geothermal bit study will help to determine thermal history of bits. Further work should be considered, however, for developing a thermal model of the bit itself. Such a model would be useful in selecting materials for bearings, seals, and other components of a drill bit.

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ATTACHMENTS

1. Exxon Production Research Co. - Quote for Thermal Simulator Computations.
2. Mobil Research and Development Corporation Letter regarding Thermal Simulator.

EXXON PRODUCTION RESEARCH COMPANY
POST OFFICE BOX 2189 • HOUSTON, TEXAS 77001

F. H. BRINKMAN
MANAGER TECHNICAL SALES

October 16, 1975

Mr. William J. McDonald
Senior Scientist
Maurer Engineering Inc.
10301 Northwest Freeway
Suite 202
Houston, TX 77018

Dear Bill:

Borehole Thermal Simulator Computer Runs

In response to your letter of September 29, 1975, we would be glad to make computer runs using our borehole thermal simulator "CIRCUS" program. I have attached an agreement giving Maurer Engineering access to this computer program on a service basis with EPR.

A computer run, as defined in the attachment to the agreement, will cover the ten specific cases that you have in mind. The total cost for ten cases (i.e., the ten combinations of variables constituting a single run) is a flat rate of \$5,000. We would provide you with data input sheets and help you fill out the first sheet for these runs. We would then make the calculations for you and give you the computer output. You could then use the data in your operations.

If the above procedure and agreement are satisfactory to you, please sign both copies of the agreement and return them to me. I will then submit them to our management for final approval. Following this, we will provide you with an EPR contact for the calculations that you would request.

Yours very truly,

F. H. Brinkman

FHB:mg
Attachments

ATTACHMENT A

Program Name, Price and Description of Computer Run

CIRCUS (Wellbore Temperature During Fluid Circulation), \$5,000/computer run.

A computer run will consist of up to ten (10) combinations of the following variables: circulating rate, mud density, heat capacity of circulating fluid, a completion scheme consisting of one combination of different pipe sizes and hole diameters to a total depth of pipe, thermal conductivity of circulating fluid, mud viscosity, surface temperature, geothermal gradient, initial fluid inlet temperature, one non-linear temperature gradient divided in up to eight increments (if a geothermal gradient is not used), and one inlet temperature profile which can be divided up into four increments.

Example:

A typical run might consider two mud densities, two circulating rates and two inlet fluid temperatures with a single combination of the other parameters ($2 \times 2 \times 2 = 8$ combinations) plus two completion schemes with a single combination of the other parameters for a total of ten (10) combinations.

EXXON PRODUCTION RESEARCH COMPANY

POST OFFICE BOX 2189 • HOUSTON, TEXAS 77001

F. H. BRINKMAN
MANAGER TECHNICAL SALES

November 18, 1975

Mr. William C. Maurer
Maurer Engineering Inc.
10301 Northwest Freeway
Suite 202
Houston, TX 77018

Dear Bill:

Attached please find a fully executed copy of our CIRCUS computer program agreement. I have also enclosed several data sheets for your use in running this program. As I indicated in my letter of October 16, we would be happy to help you fill out these data sheets for your first run. In this regard, please feel free to contact Mr. Dale Nierode to establish a mutually agreeable time.

I hope that this program will prove very useful in your operations. If you should have any questions on our agreement or the mechanics to make your runs, please give me a call.

Yours very truly,

F. H. Brinkman

FHB:mg

cc: Messrs. D. E. Nierode
L. H. Eatherton

UNSTEADY-STATE WELL TEMPERATURE PROFILE DURING CIRCULATION (CIRCUS)

DATA INPUT FORM

CARD 1

Person Requesting Run	Date	Div.	District	Well Name	Remarks
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32 33 34 35 36	37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60	61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CARD 2

Circulating Rate Gallons/Min	Mud Density #/Gallon	Heat Capacity of Circulating Fluid Cal/gm - °C	Number of Different Pipe Sizes in Hole	Number of Different Hole Diameters in Well	Thermal Conductivity of Circulating Fluid, Cal/sec-in-°C	Mud Viscosity, cp	
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60	61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80	

CARD 3

Surface Temperature °F	Geothermal Gradient °F/100 Feet	Total Depth of Pipe Feet	Initial Fluid Inlet Temperature °F	Depth Increment at which Temperature Printouts Desired, Ft.	Time to Terminate Calculations, Minutes	Circulating Time Increments at Which Printout Desired, Minutes	
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60	61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80	

CARD GROUP 4

Hole Radius, Inches	Depth from Surface Entry 1-10 Begins, Feet	Hole Radius, Inches	Depth from Surface Entry 21-30 Begins, Feet	Hole Radius, Inches	Depth from Surface Entry 41-50 Begins, Feet	Hole Radius, Inches	Depth from Surface Entry 61-70 Begins, Feet
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80			

CARD GROUP 5

Outside Radius of Pipe, Inches	Depth from Surface Entry 1-10 Begins, Feet	Outside Radius of Pipe, Inches	Depth from Surface Entry 21-30 Begins, Feet	Outside Radius of Pipe, Inches	Depth from Surface Entry 41-50 Begins, Feet	Outside Radius of Pipe, Inches	Depth from Surface Entry 61-70 Begins, Feet
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80			

CARD 6

Enter 1 in Column 3 if Temperature Increments (Card 7) used. (For Non-Linear Temperature Gradient.)

Enter Number of Inlet Temperatures (Card 8) in Columns 4-6.

1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80
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CARD GROUP 7 (Optional)

Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F	Temperature At Depth Inc. °F
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80			

CARD GROUP 8

Inlet Temperature °F	Time Since Start of Circulation for Entry 1-10	Inlet Temperature °F	Time Since Start of Circulation for Entry 21-30	Inlet Temperature °F	Time Since Start of Circulation for Entry 41-50	Inlet Temperature °F	Time Since Start of Circulation for Entry 61-70
1 2 3 4 5 6 7 8 9 10 11 12	13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80			

If a nonlinear temperature gradient is required, enter the formation temperature at each increment of depth dictated by the entry on Card 3, Columns 41-50. The first temperature increment would be at "0" depth. Use as many cards as needed to enter all required temperatures. If this input is used, Columns 11-20 on Card 3 may be left blank.

Mobil Research and Development Corporation

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ROBERT J. WATSON
MANAGER
FIELD RESEARCH LABORATORY

September 17, 1975

Dr. William C. Maurer
Maurer Engineering Inc.
10301 Northwest Freeway, Suite 202
Houston, Texas 77018

Dear Dr. Maurer:

This is in reply to your letter of August 20, 1975 covering release of the Mobil computer program for calculating temperature distribution in circulating mud columns, as referenced in SPEJ, February, 1973. I have reviewed this matter and find that it will not be expedient to make the computer program available as you suggested. To transfer the program to another research center would involve excessive time of our people in checking details, and revising documentation, and running the program here would divert staff from priority efforts.

In principle we try to avoid the necessity of reprogramming the same engineering calculations in different locations. Unfortunately, as a matter of practice we find it difficult to avoid without maintaining a large staff for standardization and communication.

Yours very truly,

W. C. Skinner

WCS:kw