APPLICATION OF THE HORNER METHOD TO THE ESTIMATION OF STATIC RESERVOIR TEMPERATURE DURING DRILLING OPERATIONS

C.Y. Chiang and Carl R.Y. Chang
Taiwan Petroleum Exploration Division
Chinese Petroleum Corporation
Miaoli, Taiwan 360

When drilling a geothermal well, it is important to know, roughly, the original formation temperature prior to setting casing pipes. Especially, the interface of the cold water zone and the hot formation should be determined during drilling so that casing and full cement jobs can be designed satisfactorily.

During drilling, heat in the formation flows into the circulating fluid. When the pump is stopped for drill pipe trips or for any other reason, the temperature of the static fluid in the hole will rise continuously. From a mathematical viewpoint, this phenomenon is similar to the pressure buildup through porous media when a fluid flowing well is shut in. The static reservoir pressure could be extrapolated from the Horner pressure-time straight line on a semilog graph; thus the static formation temperature could also be estimated in the same manner.

Unlike the pressure buildup test, the temperature recovery surveys should be performed once every 10 m interval in the open hole. This means many semilog graphs will be done: tiresome work open to miscalculation by the engineer. A hand-computer program capable of making the necessary computations is presented in Table 1. The program is written for the HP-65 hand computer. The equation used to compute the original formation temperature is derived as follows: the Horner semilog plot is usually a straight line. By the least-squares method, the straight line can be expressed as:

$$y = \frac{(\Sigma y)(\Sigma x) - n\Sigma(yx)}{(\Sigma x)^2 - n(\Sigma x^2)} X + \frac{\Sigma(xy)(\Sigma x) - (\Sigma y)(\Sigma x^2)}{(\Sigma x)^2 - n(\Sigma x^2)} \qquad (1)$$

Substituting T for y, and log $\Delta t/(t+\Delta t)$ for X, we obtain:

$$T = \frac{(\Sigma T)\left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right) - n\Sigma\left(T \log \frac{\Delta t}{t+\Delta t}\right)}{\left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right)^2 - \left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right)^2} \log \frac{\Delta t}{t+\Delta t}$$

$$+ \frac{\Sigma\left(T \log \frac{\Delta t}{t+\Delta t}\right)\left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right) - (\Sigma T)\left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right)^2}{\left(\Sigma \log \frac{\Delta t}{t+\Delta t}\right)^2 - n\Sigma\left(\log \frac{\Delta t}{t+\Delta t}\right)^2} \qquad (2)$$

where: T = temperature at certain depth
t = cumulative time of drilling fluid circulation by pumping at same depth
Δt = shut-in time
n = number of temperature surveys at same depth point

$$T = T_1 + T_2 + T_3 + \ldots + T_n$$

$$\Sigma \, \ell og \frac{\Delta t}{t+\Delta t} = \ell og \frac{\Delta t_1}{t+\Delta t_1} + \ell og \frac{\Delta t_2}{t+\Delta t_2} + \ldots + \ell og \frac{\Delta t_n}{t+\Delta t_n}$$

When $\frac{\Delta t}{t+\Delta t} = 1$, we solve Eq. 2 to obtain T, the original formation temperature at the depth point:

$$T = \frac{\Sigma\left(T \, \ell og \frac{\Delta t}{t+\Delta t}\right)\left(\Sigma \, \ell og \frac{\Delta t}{t+\Delta t}\right) - (\Sigma T)\left(\Sigma \, \ell og \frac{\Delta t}{t+\Delta t}\right)^2}{\left(\Sigma \, \ell og \frac{\Delta t}{t+\Delta t}\right)^2 - n\Sigma\left(\ell og \frac{\Delta t}{t+\Delta t}\right)^2} \qquad (3)$$

Equation 3 is used to write the hand-computer program.

EXAMPLE CALCULATION

Given Δt = 20,000 minutes:

Δt, min	$\frac{\Delta t}{t+\Delta t}$	T, °C
833	0.04	110.5
3,529	0.15	126.7
20,000	0.50	141.4

Plotting T versus $\Delta t/(t+\Delta t)$ on Fig. 1, we obtain:

$$T = 150°C \text{ when } \frac{\Delta t}{t+\Delta t} = 1$$

Calculation by the HP-65 program:

Press 20,000, A, 833, R/S, 110.5, R/S, 3529, R/S, 126.7, R/S, 20,000, R/S, 141.4, and R/S, respectively. Finally, press B. The computer displays 149.98; i.e., the answer is T = 149.98°C.

The hand-computer computation is about fifteen times faster than the semilog plot method.

Figure 2 shows the field example of Well No. CPC-CS-16T in the Chingshui Geothermal Field, I-Lan, Taiwan. It is clear that there are five depth intervals surveyed respectively by the temperature gauges during drilling. Table 2 presents data related to the temperature surveys for reference. This well was finally completed with 7 in. slotted pipe, and discharged with vertical end pipe for several days for clearing purposes. Then the well was shut in, but the noncondensible gas was bled out through a 2 in. pipe with a choke at the wellhead for prevention of hydrogen embrittlement to the wellhead system. The temperature gradient in the well was measured four months later. This is indicated by the thick solid line on Fig. 2. The temperature gauge could not go below 2,300 m, because the 7 in. slotted pipe had slipped off during setting the liner hanger while the well was under completion. It is evident that the pipe is bent at this depth. We can see the temperature at the lower section of the well is quite close to the estimated data if the actual measured temperature curve were extrapolated down to the total depth. But the upper section's temperature is higher than that estimated. It is obviously affected by heat conduction from the bottom and also by continuously bleeding free gas at the wellhead that makes the water column in the well somewhat active.

TABLE 1: THE HORNER TEMPERATURE BUILDUP COMPUTER PROGRAM FOR THE HP-65

KEY ENTRY	
LBL	RC1 7
A	X
STØ 8	STØ
0	+
STØ 1	4
STØ 2	1
STØ 3	STØ
STØ 4	+
STØ 5	5
LBL 3	GTØ 3
R/S	LBL
Enter	B
Enter	RC1 4
RC1 8	RC1 1
+	X
÷	RC1 3
f	RC1 2
log	X
STØ	—
+	RC1 1
1	Enter
STØ 7	X
Enter	RC1 2
X	RC1 5
STØ	X
+	—
2	÷
R/S	RTN
STØ	
+	
3	

TABLE 2: DATA RELATED TO THE TEMPERATURE SURVEY DURING DRILLING WELL NO. CPC-CS-16T

Survey No.	Depth Interval, m	Hole Diameter, in.	Mud Circulating Rate, liters/min	Well Head Mud Temperature	
				In	Out
1	40 - 200	17 1/2	2245	-	60 - 65
2	250 - 900	12 1/4	1912	63 - 70	70 - 82
3	920 - 2060	8 1/2	1232	67 - 72	85 - 95
4	2070 - 2550	8 1/2	1412	66 - 70	85 - 90
5	2550 - 3000	8 1/2	1540	67 - 72	87 - 92

Remark: specific gravity of mud weight = 1.20 - 1.25.

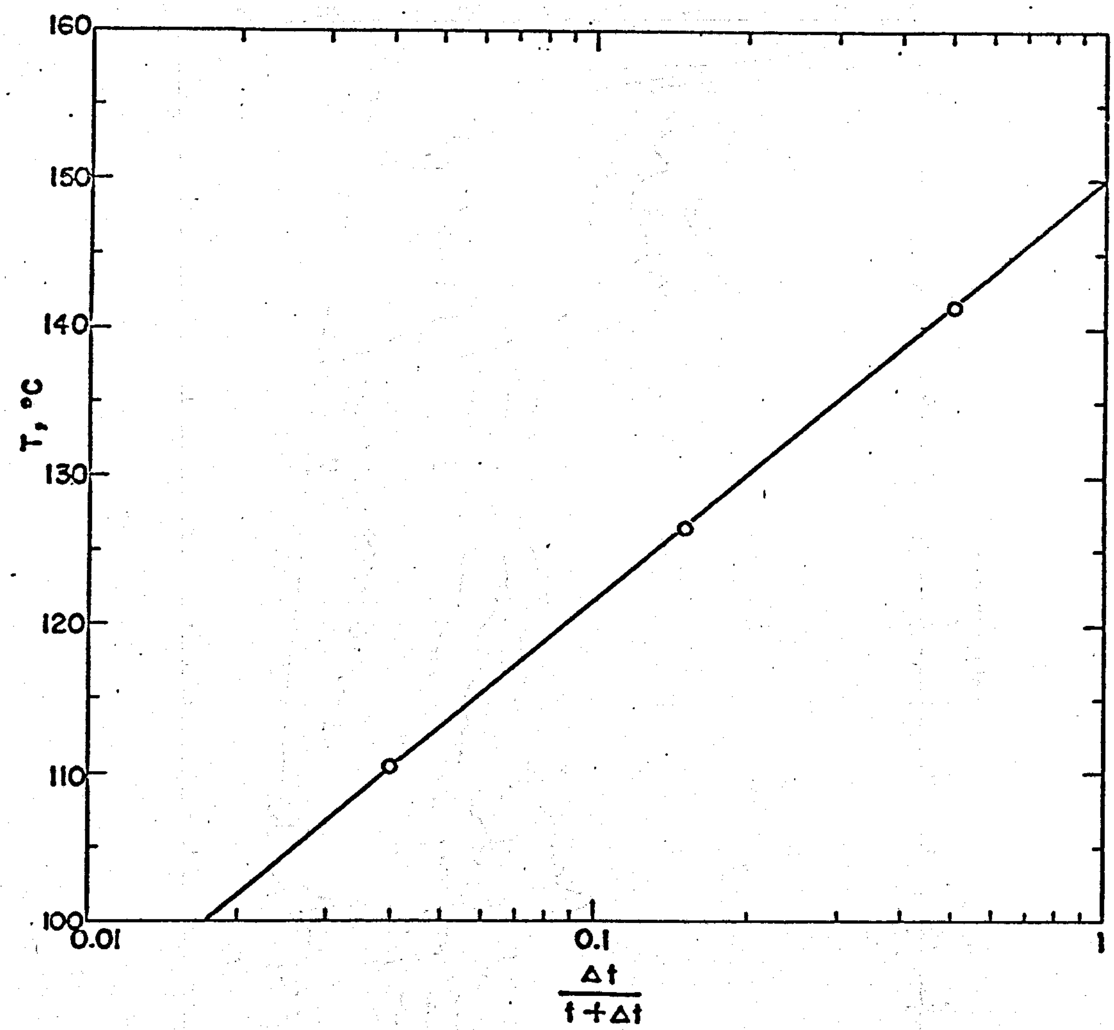

FIG. 1: HORNER TEMPERATURE-TIME PLOT

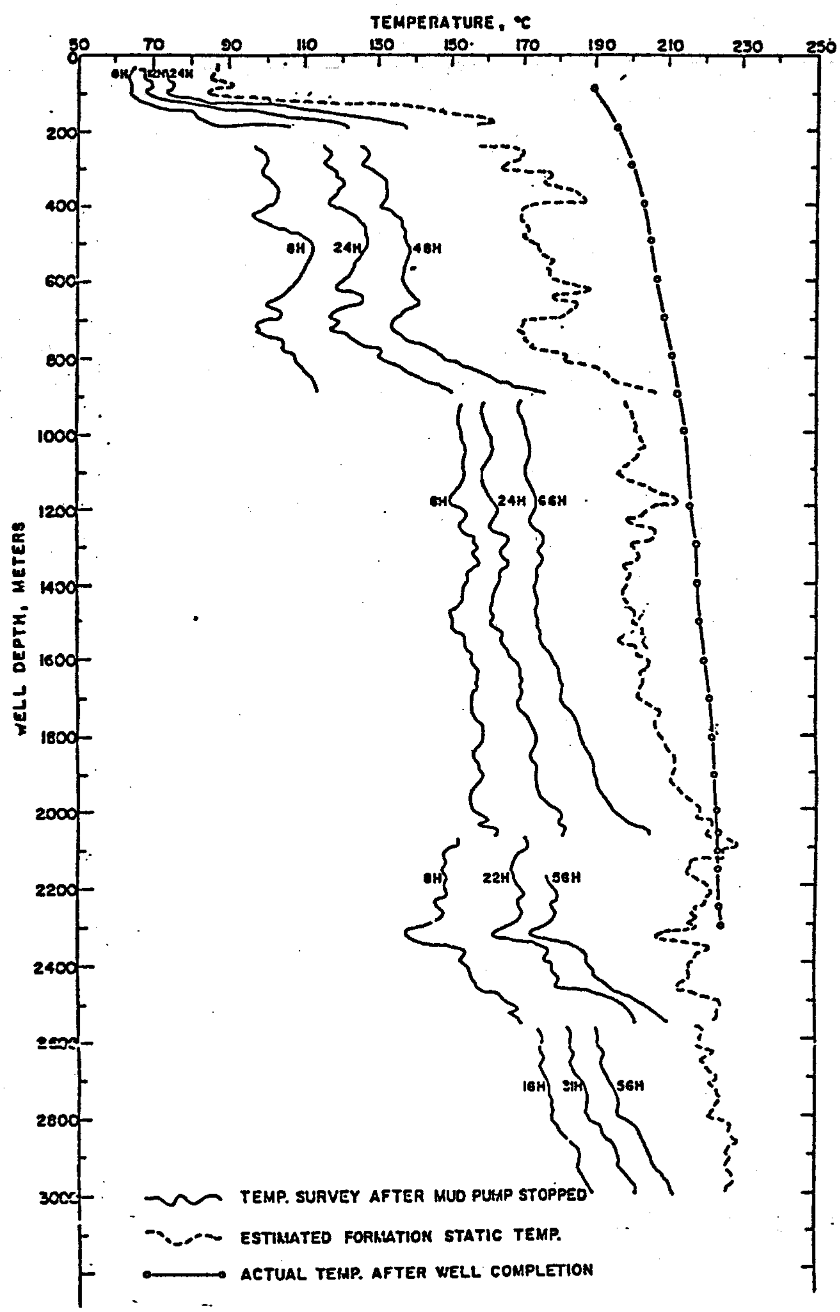

FIG. 2: TEMPERATURE SURVEYS OF GEOTHERMAL WELL NO. CPC-CS-16T