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Short Term Production Well: Estimation of the Shut-in Temperature

L.V. Eppelbaum[1] and I.M. Kutasov[2]

[1]Dept. of Geosciences, Faculty of Exact Sciences, Tel Aviv University, Ramat Aviv 6997801, Tel Aviv, Israel

[2]Consultant, BYG Consulting Co., Boston, USA

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ABSTRACT

Geophysical well logging has become a standard operation in petroleum exploration. Knowledge of the well temperature as a function of time is very important to estimate the resistivity of the formation water and the thermal stresses arising due to the difference between the wellbore temperature, and the undisturbed formation temperature. A lengthy period of time, up to one year or more, is often required to drill a deep well. In this paper, we will consider a case when the deep wellbore is utilized as a production or an injection well. The drilling and production greatly alters the temperature of the reservoir immediately surrounding the well. When a production (or injection) well is shut-in, to conduct a geophysical log, the wellbore temperature differs from the undisturbed formation temperature. The only objective of this paper is to suggest a new method of estimating the shut-in temperature.

1. INTRODUCTION

The results of field and analytical investigations have shown that in many cases the effective temperature (T_w) of the circulating fluid (mud) at a given depth can be assumed constant during drilling or production (e.g., Lachenbruch and Brewer, 1959; Jaeger, 1961; Edwardson et al., 1962; Ramey, 1962; Kutasov et al., 1966; Raymond, 1969; Kutasov and Eppelbaum, 2015). Here we should note that even for a continuous mud circulation process the wellbore temperature is dependent on the current well depth and other factors. The term "effective fluid temperature" is used to describe the temperature disturbance caused to formations while drilling. Lachenbruch and Brewer (1959) in their classical paper have shown that the wellbore shut-in temperature mainly depends on the amount of thermal energy transferred to (or from) formations. Let us assume that drilling was followed by a short production or injection period. The average circulating fluid temperature (at a given depth) T_c while drilling changed to T_p when production (injection) started at time t_c (Figure 1). We will consider production wells where the ratio production time to drilling mud circulation time (t_p/t_c) is relatively small. For very large values of t_p/t_c the effect of the drilling mud circulation period on the thermal disturbance of formation can be neglected.

Here we will neglect the time gap between cessation of drilling operations and beginning of production. The change in wellbore temperature from T_c to T_p causes an additional change in the distribution of temperature around the wellbore. The function $T(r,t = t_p)$ during the production period can be calculated by adding to the temperature difference caused by T_c, an additional difference caused by $(T_p - T_c)$ beginning at time $t = t_c$.

2. RADIAL TEMPERATURE DISTRIBUTION

Even if a single value is used for T_c during the entire drilling period, the wellbore temperature is strongly different from T_p during the production period. If the same well is utilized for injection at the end of the production period, the wellbore temperature changes again. With some assumptions, Carslaw and Jaeger's integral solution of the heat conduction equation for a solid cylinder can be used to estimate $T(r, t)$ in any period provided the temperature distribution function, $f(r)$, at the beginning of the period is known. Carslaw and Jaeger's solution for $T(r, t)$ is very lengthy and unsuitable for evaluation. Gogoi and Kutasov (1986) presented a simple method of approximating $T(r,t)$ around an uncased well with a history of variations in wellbore temperature. The method is based on the extension of the approximate solution (Kutasov, 1968) for $T(r, t)$ during the drilling period to the production period and/or the injection period by the use of the principle of superposition. By applying the principle of the superposition (Gogoi and Kutasov, 1986) the following equation was obtained:

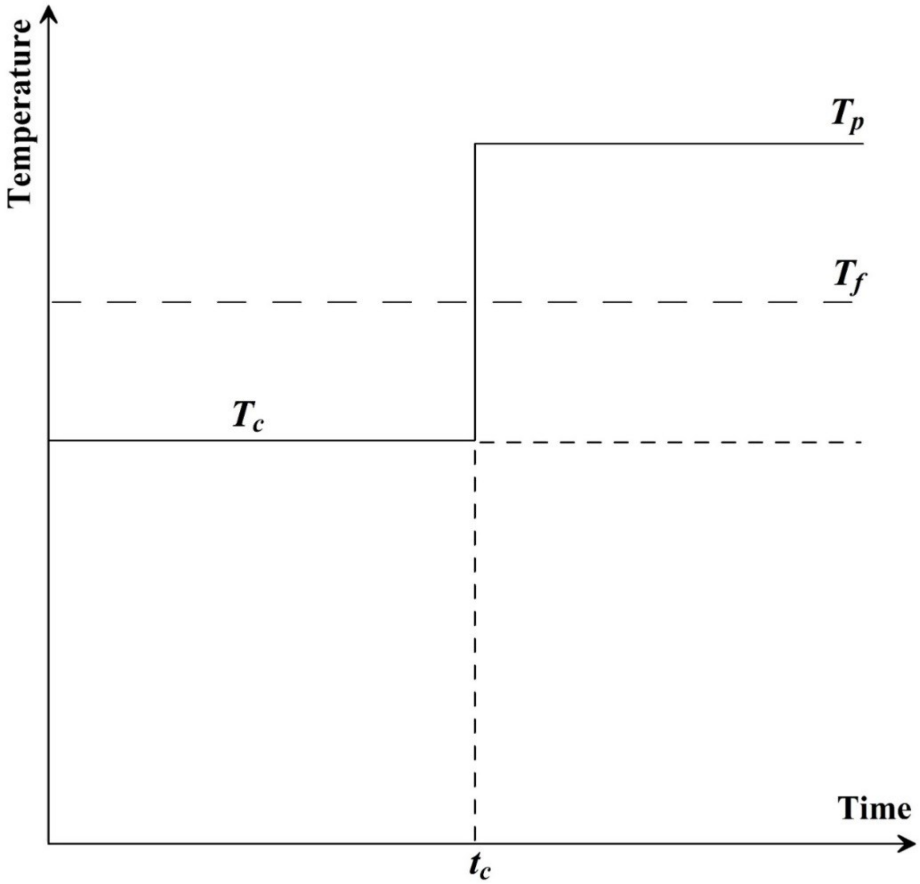

Figure 1: Wellbore temperature history of a well

$$T(r,t_c + t_p) = Tp - (T_c - T_f)\frac{\ln r_D}{\ln R_{\text{int}}} - (T_p - T_c)\frac{\ln r_D}{\ln R_{inp}}, \tag{1}$$

$$R_{\text{int}} = 1 + 2.184\sqrt{t_{Dt}}, \quad R_{inp} = 1 + 2.184\sqrt{t_{Dp}}, \quad r_D \le R_{inp}, \tag{2}$$

$$\text{at } r_D > R_{inp},\ T(r,t_c + t_p) = T_f m, \quad \text{at } 1 > r_D > 0,\ T(r,t_c + t_p) = Tp,$$

$$r_D = \frac{r}{r_w}, \quad t_{Dt} = \frac{a_f(t_c + t_p)}{r_w^2}, \quad t_{Dp} = \frac{a_f t_p}{r_w^2},$$

where r_w is the well radius, r_D is the dimensionless radial distance, a_f is the thermal diffusivity of formations, R_{int} is the radius of thermal influence at the time $t_c + t_p$. Let us to introduce the dimensionless temperature

$$T_D = \frac{T(r,t_c + t_p) - T_p}{T_f - T_c} = \frac{\ln r_D}{\ln R_{\text{int}}} + \frac{T_p - T_c}{T_f - T_c}\frac{\ln r_D}{\ln R_{inp}}. \tag{3}$$

From Eq. (1) for the drilling period (when $t_p = 0$, $T_p = T_c$) we obtain the well-known relationship for the dimensionless radial temperature (Kutasov, 1968; Kutasov, 1999).

$$T_{Dc} = \frac{T(r,t) - T_f}{T_c - T_f} = 1 - \frac{\ln r_D}{\ln R_{\text{int}}}, \quad t_{Dc} = \frac{a_f t_c}{r_w^2}, \quad R_{inc} = 1 + 2.184\sqrt{t_{Dc}}. \tag{4}$$

As is shown in Table 1, Eq. (1) satisfactory approximates the radial temperature distribution during the production period.

Table 1: Comparison of $T(r,t)$ during production period calculated with Eq. (1) – first line and numerical solution (computer program "Temp") – second line. Input data: r_w =0.1 m, T_f = 120°C, T_c = 75 °C, T_p = 150 °C, a_f = 0.005 m²/hr, t_c = 750 hrs (after Gogoi and Kutasov (1987), with modifications)

Production time, hours	*r*, meters					
	0.2	0.5	0.8	1.0	5.0	10.0
5.0	122.06 118.22	91.34 94.15	97.57 97.63	100.53 100.54	120.0 120.0	120.0 120.0
10.0	127.89 124.64	98.67 99.42	97.55 97.40	100.50 100.66	120.0 120.0	120.00 120.00
20.0	132.35 129.70	109.01 106.41	97.50 101.34	100.45 101.80	120.0 119.97	120.00 120.00
50.0	136.75 134.76	119.23 115.71	110.24 108.53	105.97 106.70	120.0 119.92	120.00 120.00
100.0	139.25 137.68	125.03 121.85	117.74 114.86	114.27 112.32	120.0 119.87	120.00 120.00
200	141.20 140.04	129.57 127.04	123.60 120.85	120.77 118.27	120.0 119.83	120.00 120.00
500.0	143,09 142.40	133.97 132.39	129.28 127.40	127.05 125.13	118.68 118.34	120.00 120.00
1000.0	144.10 143.62	136.30 135.23	132.29 130.97	130.39 128.99	116.75 119.65	120.00 120.00
2000.0	144.82 144.77	137.96 137.16	134.45 133.43	132.78 131.67	120.74 121.00	120.00 120.00

3. DETERMINATION OF THE SHUT-IN TEMPERATURE

To determine the temperature in borehole (r = 0) after the time $t = t_c + t_p$ we use the solution of the diffusivity equation that describes cooling along the axis of a cylindrical body with known initial temperature distribution (T'_D), placed in an infinite medium of constant temperature (Carslaw and Jaeger, 1959; p. 260).

$$T_{sD} = \frac{1}{2at_s}\int_o^\infty \exp\left(-\frac{\tau^2}{4at_s}\right) T'_D(\tau,t_D)\tau\, d\tau, \qquad (5)$$

$$T_{sD} = \frac{T_s(0,t_s) - T_f}{T_m - T_f},$$

$$\left\{\begin{array}{l} T_D^{'}(\tau,t_D)=T_D(\tau,t_D);\ r\geq r_w,\quad (\text{Eq. (3)},\quad \tau=r_D,\quad R_{inp}\leq r_D\geq 1\ ), \\ T_D^{'}(\tau,t_D)=\dfrac{T_f-T_p}{T_f-T_c},\quad r_D>R_{inp},\quad T_D^{'}(\tau,t_D)=0,\quad 0<r_D\leq 1, \end{array}\right\},$$

where τ is the variable of integration, t_s is the shut-in time, and T_s is the shut-in temperature. The integration of Eq. (5) at similar conditions was conducted earlier (Kutasov, 1999).

We obtained

$$T_{sD}=1-\frac{\dfrac{T_c-T_f}{T_p-T_f}\left[-Ei\left(-pR_{\text{int}}^2\right)+Ei(-p)\right]}{2\ln R_{\text{int}}}-\frac{\dfrac{T_p-T_c}{T_p-T_f}\left[-Ei\left(-pR_{inp}^2\right)+Ei(-p)\right]}{2\ln R_{inp}},\qquad (6)$$

$$T_{sD}=\frac{T(0,t_s)-T_f}{T_p-T_f},$$

$$T_s=T(0,t_s)=T_{sD}\left(T_p-T_f\right)+T_f,\qquad (7)$$

where T_{sD} is the dimensionless shut-in temperature, and Ei is the exponential integral.

4. EXAMPLE OF CALCULATIONS

We conducted calculations after Eq. (7) (Figure 2). The following parameters were assumed: the temperature of drilling fluid at a given depth T_c = 75.0 °C, the temperature of production fluid T_p = 150.0 °C, duration of drilling mud circulation t_c = 750 hrs, time of production 2000 hrs and thermal diffusivity of formation, a = 0.0050 m^2/hr.

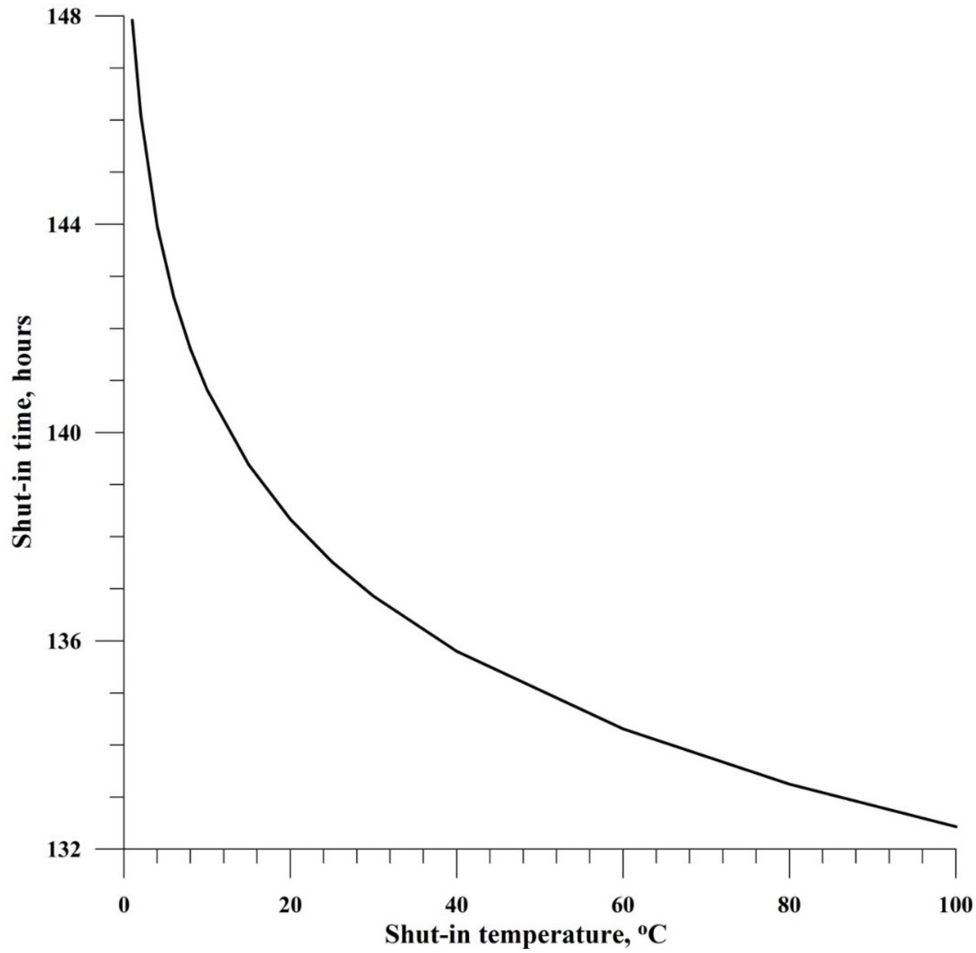

Figure 2: Shut-in temperature versus time

5. CONCLUSIONS

A method of estimation of the shut-in temperature is suggested. A situation when the deep wellbore is utilized as a production *or* an injection well is considered in detail. The method takes into account the thermal disturbance of formations during drilling and production.

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