PRESSURE AND TEMPERATURE BUILDUP IN GEOTHERMAL WELLS

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Two-phase flow and heat transfer influence the pressure-time response of hot-water wells. The methods developed for pressure buildup analyses in oil, gas, and cold water reservoirs are not completely applicable in hot-water reservoirs.

Mathematical synthesis is necessary to build existing two-phase flow theory, heat transfer theory and steam thermodynamics into a system for analyzing hot-water well pressure transients that is equivalent to methods available for oil and gas reservoirs.

HOT WATER FLASHING IN THE RESERVOIR CAUSES TEMPERATURE CHANGES

When flowing reservoir pressure falls below the saturation pressure corresponding to the reservoir temperature, hot water flashes in the reservoir. As the hot water flashes, fluid temperature drops in response to the prevailing pressure. Consider conditions prevailing in a hot-water well:

Static reservoir temperature = 593°F
Static reservoir pressure = 1823 psia
Steam saturation pressure corresponding to 593°F = 1464 psia

Because the reservoir pressure is greater than the saturation pressure, there is no steam in the static reservoir conditions.

Bottom-hole flowing pressure = 450 psia

The bottom-hole flowing pressure is less than the saturation pressure; therefore, as it flows toward the well, part of the hot water flashes into steam. From thermodynamic considerations, the temperature of the steam-water mixture must correspond to 450 psia.

Saturation temperature corresponding to 450 psia = 456°F

Thus the fluid temperature has declined from 593°F to 456°F. But the rock temperature was 593°F. The difference in the rock and the fluid temperature causes the heat to flow from the rock to the steam-water mixtures.

RATE OF HEAT TRANSFER FROM TEMPERATURE BUILDUP

During pressure buildup measurement in a hot-water well, temperature usually is measured along with the pressure. An interpretation of the temperature buildup can give us the rate of heat transfer in the rock, by conduction, toward the wellbore.

Fig. 1 shows temperature buildup graph in a hot-water well. The slope on this graph is given by the following relation:

$$m = \frac{2.303\ q}{4\ \pi\ kh}$$

where q = rate of heat transfer, Btu/hr
k = thermal conductivity of the rock, Btu/hr-ft-°F
h = formation thickness, ft
m = slope on the semi-log paper, °F/cycle

The slope on Fig. 1 is 48°F/cycle. Using k = 2 Btu/hr-ft-°F:

$$\frac{q}{h} = (48)\ (4\pi)\ (2)/2.303$$

$$= 525 \text{ Btu/hr-ft.}$$

This provides evidence of heat transfer. During the production period, this heat is available to raise the enthalpy of the produced fluid.

The above calculation of the heat transfer rate assumes heat transfer to the wellbore by conduction only. In fact, the heat is transferred both by conduction and by the fluid transport. Thus the component of heat transferred by conduction alone will be less than 525 Btu/hr-ft.

FLASHING IN THE RESERVOIR GIVES RISE TO A REGION OF TWO-PHASE FLOW

The bottom-hole flowing pressure of this hot-water well is 450 psia whereas the steam saturation pressure corresponding to the static reservoir temperature of 593°F is 1464 psia. The reservoir pressure increases away from the wellbore from 450 psia to the original pressure of 1823 psia. At some distance from the wellbore, the pressure will exceed 1464 psia and that point will mark the boundary between two-phase and single-phase flow.

FOR PRESSURE ANALYSIS, A STRAIGHT LINE CANNOT BE FOUND

Fig. 2 presents pressure transient data, measured at the same time as the temperature data, Fig. 1. Pressure, on Fig. 2, is plotted as a function of log $[(t + \Delta t)/\Delta t]$ for an oil reservoir Horner-type analysis. For this analysis, a straight-line portion of the graph is selected; its slope is inversely proportional to reservoir permeability.

This buildup lasted 550 hours. But we see a curve rather than a straight line. Unfortunately, there are gaps in the observations. But data gathering is a part of the problem in hot-water wells.

The buildup data presented in Fig. 2 do not show wellbore fill up or linear flow effects on a log-log type curve match. This makes it difficult to find the onset of radial flow or, in other words, the start of a semi-log straight line. One could draw more than one straight line through the data on Fig. 2. Although I have drawn a line of slope 121 psi/cycle, I cannot find sound justification for this line.

STEAM-WATER INTERFACE TENDS TO MASK THE END OF THE STRAIGHT LINE

Drainage areas in hot-water wells generally have two boundaries. The first boundary is the steam-water interface which is created as a result of the flowing reservoir pressure falling below the saturation pressure. The extent of the steam-water boundary is controlled, among other factors, by the flowing pressure, the initial reservoir pressure and temperature, and the rate of heat transfer from the rock to the fluid. The second boundary is the drainage boundary of the system; it could be closed, held at a constant pressure, or a mixed boundary.

Pressure buildup is affected more by the steam-water interface than by the drainage boundary. If the steam-water interface is not far from the wellbore, it will probably interfere with the straight line portion of the buildup. I think that is what is happening in the buildup presented in Fig. 2.

HEAT TRANSFER INTERFERES WITH DRAINAGE BOUNDARY EFFECTS

Under flowing conditions, the fluid temperature is less than the reservoir temperature. The resulting heat transfer causes temperature gradients in the rock. As the well is shut in, we have the phenomenon of temperature buildup in the rock along with the pressure buildup in the fluid. After some time, when the temperature and pressure have stabilized, the fluid in the wellbore boils. The boiling causes the temperature to drop, which, in turn will give rise to a new boiling cycle when the temperature has stabilized.

The pressure fluctuations caused by boiling interfere with the drainage boundary effects. This does not mean that the drainage boundary effects can be observed with certainty if the boiling did not occur. I think steam-water boundary effects will dominate any drainage boundary effects.

HOT-WATER BUILDUPS DIFFER FROM GAS/OIL BUILDUPS

There are significant differences between the buildups in hot-water and gas/oil wells. These are some of the differences:

1. Gas/oil systems generally are porous and have well-defined upper and lower boundaries. Most of the wells have complete penetration. On the other hand, hot water generally flows through fractures. Wells have partial penetration. We have two phases flowing near the wellbore and only single phase flowing some distance away from the wellbore. After shut-in, the two phases tend to become single phase all over.

2. In hot-water reservoirs, heat transfer interacts with the reservoir pressures and saturations. It is of no consequence in the oil/gas reservoirs.

3. Boiling tends to mask the boundary effects in hot-water wells.

FURTHER WORK IS NEEDED

We need to have an interpretative method for use in hot-water wells. Analytical solutions to the fluid and heat diffusivity equations are not likely to answer all the questions. We probably will need the help of a two-dimensional radius-height computer model to develop required information.

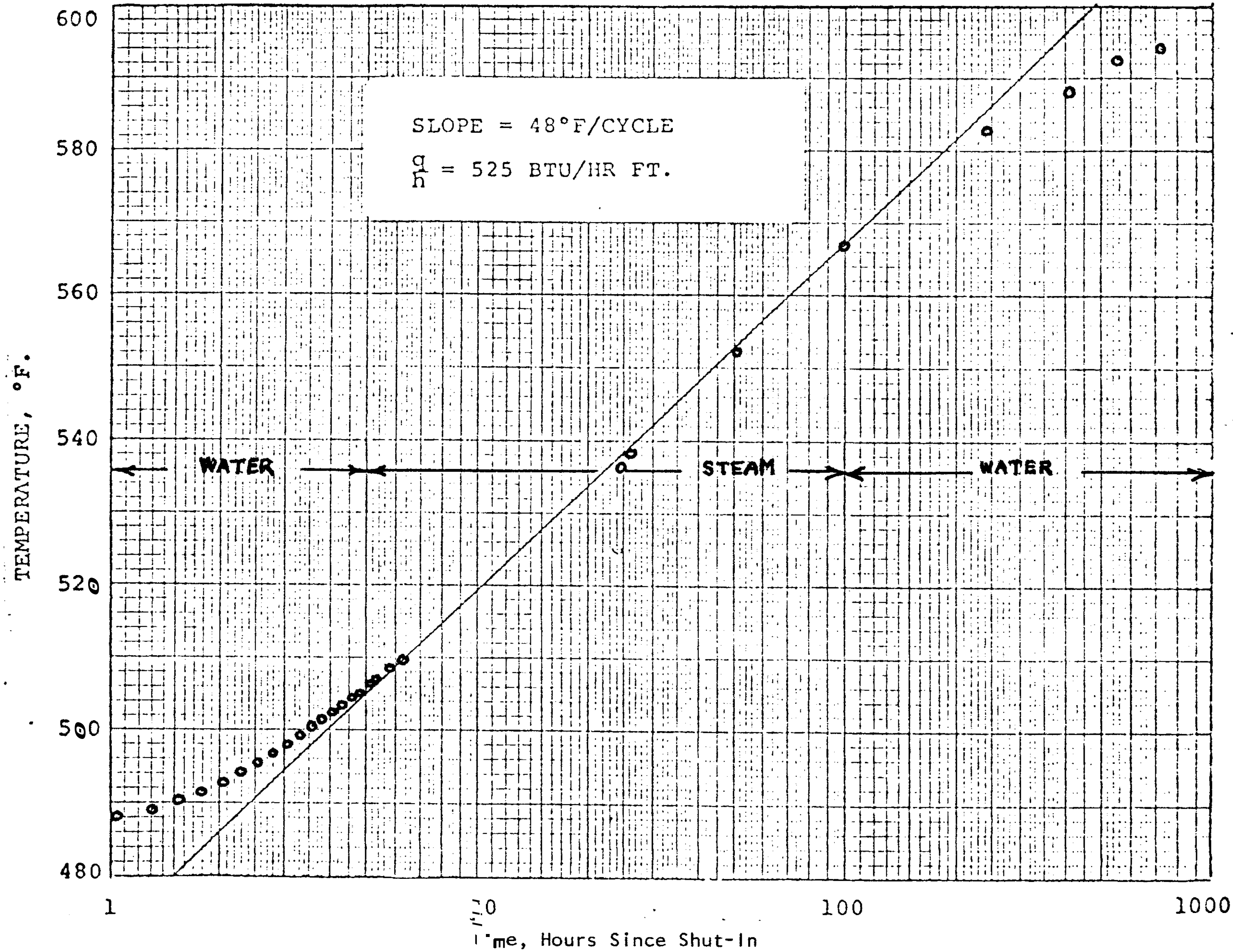

Figure 1 Temperature Build-Up in a Hot-Water Well.

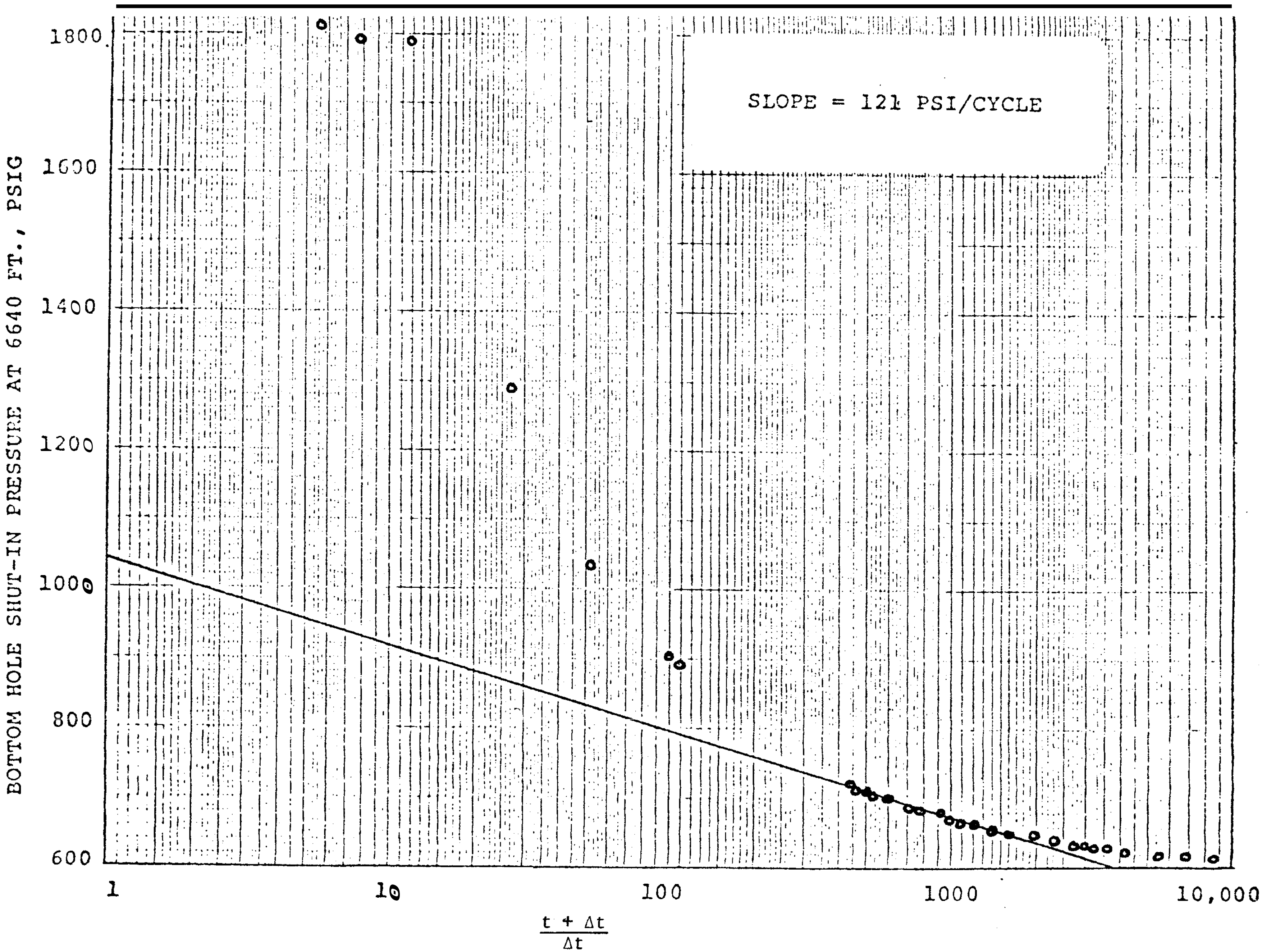

Figure 2 Pressure Buildup in a Hot-Water Well