SENSITIVITY STUDY OF VARIABLES AFFECTING FLUID FLOW IN GEOTHERMAL WELLS

by

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INTRODUCTION

It is generally believed that for commercial geothermal wells, flow rates are sufficiently high so that the formation around the well comes to thermal equilibrium in a matter of days or weeks. After thermal equilibrium is established, very little temperature drop takes place in such wells as hot water (single phase) rises from the bottom to the top of the well. A two phase geothermal fluid is thought to undergo temperature decline in a commercial well bore as flowing pressure declines according to the water-steam vapor pressure curve. The common belief is that for commercial wells, one can ignore heat conduction from the well to the formation for all practical purposes. Hence, one publication[1] presented a geothermal well simulation approach without consideration of heat conduction. Gould[2], however, had pointed out the influence of heat conduction in the performance of geothermal wells. Experience shows that for commercial wells needed for electrical power generation where the flow rates involved are tens of thousands of pounds per hour, it is often acceptable to ignore heat conduction. Whether such simplification is reasonable for wells for non-electrical geothermal projects has not been studied. Such wells are produced at a much smaller rate than wells for electrical power generation. It is quite likely that heat conduction and gravity head will have much more influence than the frictional pressure drop and acceleration effect on such low yield wells.

The authors simulated behavior of flow in such a well using a numerical well bore simulator[3], an older version of which had been described before[4]. The well studied was Bostic 1-A at Mountain Home, Idaho. This well had been chosen as a supply well for a USDOE-financed feasibility study of a direct geothermal use program[5]. The well is 9,678 feet deep and 8 3/4 inches in diameter with a maximum temperature of 372°F at 8,898 ft[5]. A drill stem test was inconclusive and the well had not flowed before. It was decided to forecast the condition of the well effluent for various assumed flow rates so that, if the well could be made to flow, optimum production condition could be specified and the adequacey of the well for the proposed project assessed.

WELL BORE HYDRAULICS AND THERMODYNAMICS

The simulating model used in this study[3,4] takes into account the flow of hot water (or hot water-steam mixture) in a well bore and calculates the temperature, pressure, enthalpy, and the steam quality at any point in the well bore if the pertinent data are given for the downhole condition. For example, given the flow rate, temperature, and pressure at the bottom of the wells and the diameter of the casing, the program can calculate the pressure, temperature, and steam quality at the wellhead and at any point within the well. The program takes into account pressure drop due to change in gravity head, friction, and acceleration, liquid holdup, heat transfer between the liquid and the rock outside the casing, phase change, and the time dependency of heat transfer. For accurate calculations, two other parameters are required in this program; however, if not known, they can be approximated. One other parameter is an "overall heat transfer coefficient," which varies from well to well, with depth in the same well, and with flow rate in the same well. If a measured flowing temperature profile in the well is available, the heat transfer coefficient can be calculated. If the coefficient is unavailable, a number for this quantity can be assumed from experience.

Initially, the flowing pressure and temperature profile in the well bore for a given flow rate should be determined. Figure 1 shows the calculated temperature and pressure profiles in this well for a flow rate of 500 gpm (2,725 cu m/day). Also shown in this figure is a static temperature profile in the well bore as obtained from the temperature survey. The bottom hole pressure for this calculation was assumed to be 4,000 psi (281 kg/sq cm) at 9,000 feet (2,743 meters). The drillstem test showed a final shut-in pressure of 3,750 psi (264 kg/sq cm); however, the shut-in pressure is probably significantly higher than 3,750 psi (264 kg/sq cm). Also, during the drillstem test the hydrostatic mud pressure in the well bore was reported to be around 4,109 psi (289 kg/sq cm). Hence, an upper limit of the reservoir pressure should be around 4,100 psi (288 kg/sq cm). The flowing bottom hole pressure should be substantially smaller than the static reservoir pressure because of the need for pressure drop at the well-reservoir interface. As can be seen on Fig. 1 the calculated flowing pressure profile is a straight line indicating that the water does not flash into steam. The curvature of the flowing temperature profile toward the upper part of the well is caused by heat transfer between the fluid in the well bore and the rock outside.

Figure 2 shows another set of calculated profiles of pressure and temperature in this well at a flow rate of 600 gpm (3,270 cu m/day). But for this case, a more likely pressure value was assumed: 3,500 psi (246 kg/sq cm) at 9,000 feet (2,743 meters). In this case, the flowing pressure gradient becomes sharply lower at about 400 feet (122 meters) indicating a flashpoint at that depth. The wellhead pressure is much lower and temperature slightly higher than would be seen if the fluid did not flash in the well bore. It is quite likely that the water will flash in the well bore. It is difficult to evaluate the flowing bottom hole pressure in the well for lack of knowledge of the static reservoir pressure and the permeability around the well bore.

SENSITIVITY STUDY

In order to understand the sensititvity of the wellhead fluid condition to the various parameters, the well bore simulation program was run a large number of times with various values of some of the basic parameters. For example, Figure 3 shows a plot of the calculated temperature of the fluid at the wellhead versus production rate for the case of a bottomhole pressure of 4,000 psi (281 kg/sq cm) (non-flashing case). In this case, the pressure curve goes through a maximum indicating that there is an optimum production rate which will maximize the wellhead pressure. The temperature curve is monotonically increasing up to 1,200 gpm (6,540 cu meters/day), beyond which it practically coincides with the bottomhole temperature. This indicates that for a flow rate higher than 1,200 gpm (6,540 cu m/day) the rate of heat transfer from the fluid to the rock outside is negligible. It should be noted that above 400 gpm flowing pressure decreases with increasing flow rate as to be expected from deliverability considerations. Below 400 gpm, the flowing pressure increases with increasing flow rate because temperature increases with flow rate in this range and hence the gravity head decreases. Figure 4 shows a plot of the calculated water enthalpy at the wellhead versus flow rate for the non-flashing case, the shape of which is very similar to the temperature curve in Fig. 3.

It appears that beyond a flow rate of about 1,500 gpm (8,175 cu m/day), the enthalpy of the fluid at the wellhead is essentially the same as the bottomhole fluid enthalpy. It is obvious that the quality of the wellhead water increases rapidly with increasing flow rate up to a flow rate of about 600 gpm (3,270 cu m/day), beyond which the increase of water enthalpy with increasing flow rate is very slow. Thus, from a thermodynamic standpoint, a flow rate of 600 gpm (3,270 cu m/day) or higher would be the most efficient means of producing this well; whereas, if maximizing the wellhead pressure is a goal, then a flow rate of about 450 gpm (2,453 cu m/day) is optimum. Figure 5 presents the calculated depth at which flashing takes place versus the production rate for the flashing case, 3,500 psi (246 kg/sq cm) bottom hole pressure at 9,000 feet (2,743 meters). The depth of flashing increases rapidly until the flow rate of about 200 gpm (1,090 cu m/day) is reached. Beyond that the depth of flashing is a linear function of the production rate. Figure 6 shows the calculated wellhead pressure and temperature versus flow rate for the flashing case. In this case, both the temperature and pressure curves go through a maximum for the following reason. At lower flow rates, there is more cooling due to heat transfer to the surroundings. But at high flow rates flashing takes place at greater depth and steam flowing up from a greater depth cools down more, creating a declining trend of temperature versus flow rate beyond the maximum. Thus, in this case, considering Fig. 6, a production rate of 300 gpm (1,635 cu m/day) is perhaps the most preferable. Figure 7 shows the calculated amount of steam in the effluent and enthalpy of steam-water mixture at the wellhead as a function of production rate. As is expected, as the production rate increases, the wellhead steam quantity increases rapidly. However, the mixture enthalpy at the wellhead increases up to a flow rate of little over 200 gpm (1,090 cu m/day) beyond which the mixture enthalpy reaches the limit (equal to the enthalpy of the bottomhome water). Thus, considering enthalpy, a minimum flow rate of 200 gpm (1.090 cu m/day) appears desireable.

At this point, it is interesting to compare the flashing versus the non-flashing cases. It should be remembered that the non-flashing case can be considered similar to the situation where a pump may be set up in the well to prevent flashing. From Figs. 6 and 7, it is apparent that a production rate of about 300 gpm (1,635 cu m/day) is the optimum flow rate for the flashing case. At this flow rate, the mixture enthalpy is practically the same as enthalpy at the bottomhole conditions, namely 345 Btu per pound. For the non-flashing case, for a production rate of 300 gpm, the enthalpy of the wellhead water will be only 243 Btu per pound as shown in Fig. 4. In Table 1, it is clear that at 300 gpm the flashing case provides higher enthalpy than the non-flashing case. However, the pressure at the wellhead is higher in the non-flashing case. So if surface pressure is a consideration, then it may be worthwhile installing a down-hole pump to prevent flashing in the well bore. It should also be noted that in the flashing case, the wellhead fluid has a higher temperature and that these comparisons are specific to the well conditions chosen.

CONCLUSION

It is apparent from this study that the condition of the wellhead effluent is a function not only of the reservoir and well characteristics, but also of the operating conditions. For low yield wells such as the one studied here, a sensitivity study of the well bore flow can be helpful in project optimization.

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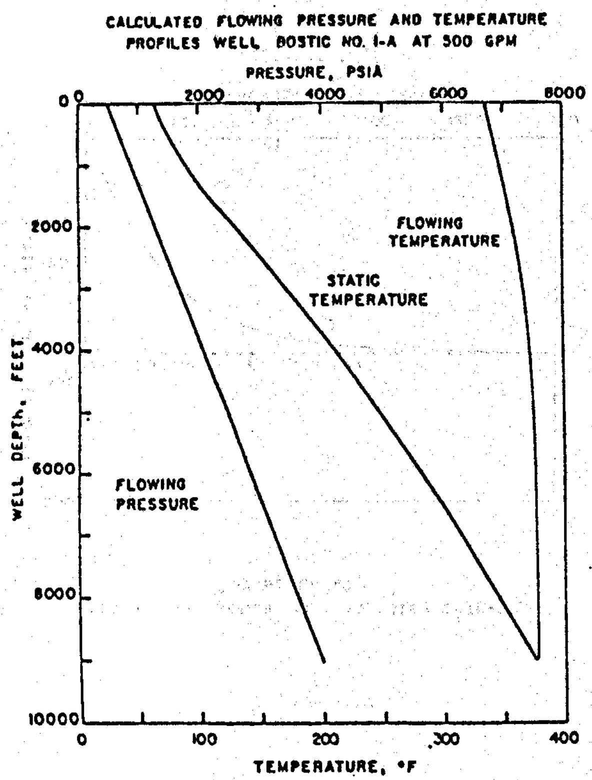

FIGURE 1

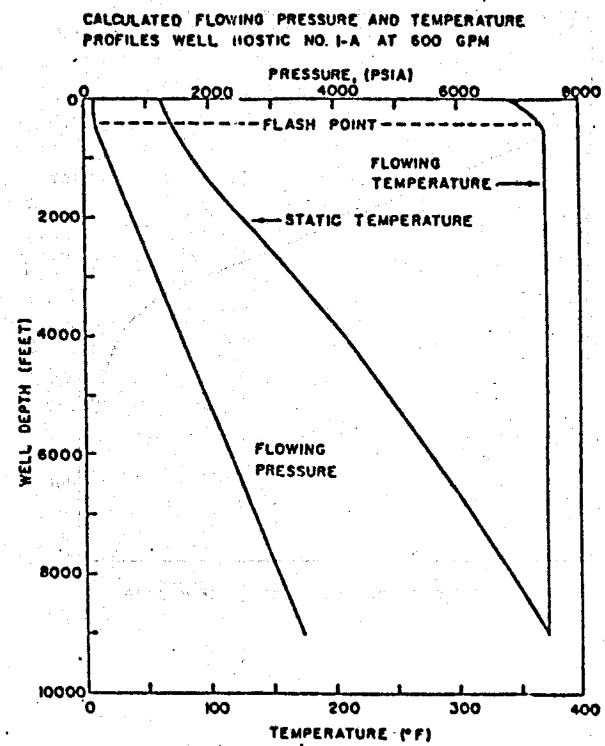

FIGURE 2

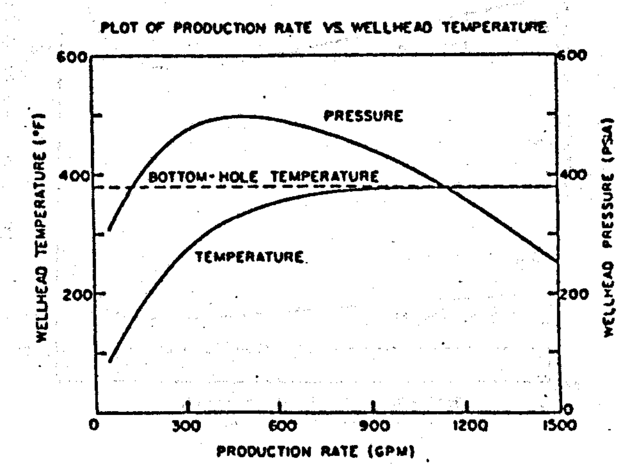

FIGURE 3

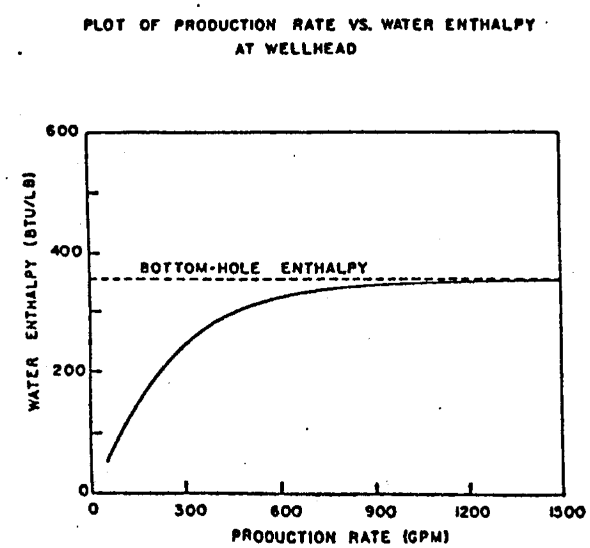

FIGURE 4

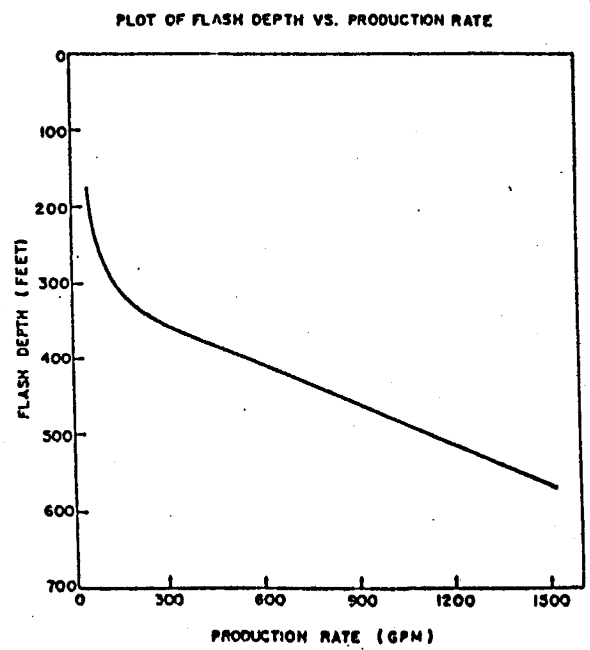

FIGURE 5

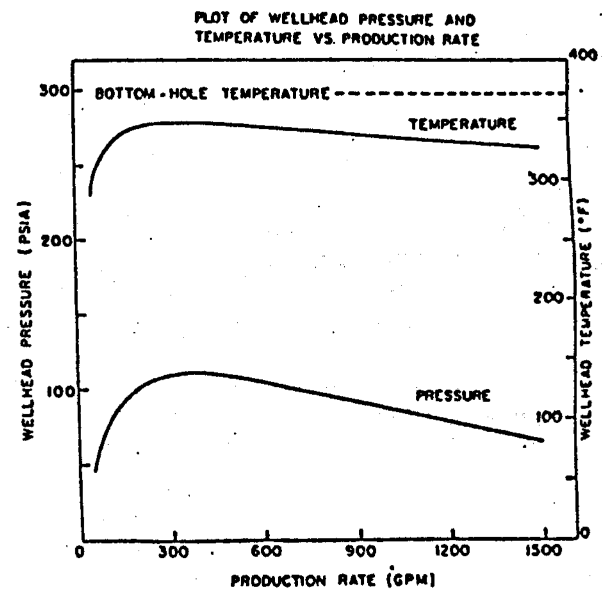

FIGURE 6

PLOT OF PRODUCTION RATE VS. WELLHEAD STEAM QUANTITY
AND MIXTURE (STEAM AND WATER) ENTHALPY

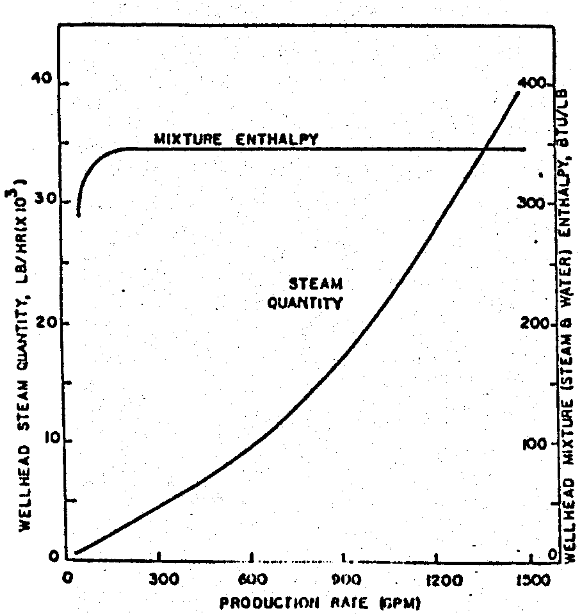

FIGURE 7

COMPARISON OF TWO PRODUCTION SCHEMES

Flow Rate: 300 gallons/minute

Bottomhole conditions refer to 9,000 Ft depth

	Flashing	Non-Flashing
Bottomhole Pressure (psia)	3,500	4,000
Bottomhole Temperature (°F)	372	372
Bottomhole Enthalpy(Btu/lb)	345	345
Flashing Depth(Ft)	353	-
Steam Quantity at Wellhead (lbs./hour)	4,500	0
Wellhead Pressure(psia)	110 *	480
Wellhead Temperature (°F)	347	270
Wellhead Enthalpy (Btu/lb)	345	239

* less than vapor pressure because already flashed

TABLE 1