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EFFECT OF MEASURED WELLHEAD PARAMETERS AND WELL SCALING ON THE COMPUTED DOWNHOLE CONDITIONS IN CERRO PRIETO WELLS

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INTRODUCTION

The primary objective of modeling a geothermal system is to be able to predict with some confidence the energy production capacity and longevity of the field under various production and injection scenarios. To achieve this goal, a modeler needs to construct a comprehensive mathematical model based on available data and validate this model against the production history of the field. This, in turn, requires the data associated with the evolution of the field due to its exploitation. Typically, the information related to the variations in the mass flow rate, enthalpy, pressure, temperature and fluid saturation as a function of time is used to validate the model. The production data is routinely measured at the wellhead whereas most reservoir models compute the changes in the temperature, pressure, enthalpy, fluid velocity and other physical properties of the fluid at the sandface. To validate any model, wellhead data must be corrected to reflect the downhole conditions. In this paper, we shall confine ourselves to the discussion of computing bottomhole pressures from the measured wellhead data by using a wellbore model. Several wellbore models which compute wellhead conditions from the given bottomhole data have been cited in the literature. (Sanyal, et al., 1979; Aydelotte, 1980; Gould, 1974). Such calculations are of interest in predicting the conditions under which an optimum production could be obtained from a given well. This approach does not suit us since our primary goal is to study the evolution of the field due to production. The following paragraphs are devoted to the discussion of the wellbore model and its describing equations, comparison between the computed and measured pressures and the effect of measured wellhead parameters on the downhole pressures in the well. Finally a wellbore model with multiple inside diameters is discussed and the effect of well scaling on the bottom hole pressures is studied.

WELLBORE MODEL

The steady state computer program WELFLO used in this study calculates the bottomhole conditions if the wellhead conditions such as mass flow rate, pressure and enthalpy (or dryness fraction) are prescribed. The length of open interval and heat loss from the well bore are also considered in the program. However, the effect of the radial pressure gradient responsible for inflow to the well is not taken into account. The total mass inflow to the well is assumed to be distributed evenly throughout the open interval. Also, in-place internal energy in the open interval is assumed constant. The equations, describing a transient two-phase flow through a well are discussed in Miller (1979). The steady-state equations of mass, momentum and energy as obtained from that set for a constant diameter well are as follows:

$$\frac{\partial}{\partial x}(\rho u) = 0 \tag{1}$$

$$\frac{\partial p}{\partial x} = -\rho g - \frac{f\rho u^2}{2D_i} - \frac{\partial}{\partial x}\,(\rho u^2) - \frac{\partial}{\partial x}\left[\frac{(1-\alpha)\alpha\rho_\ell\rho_g\,(u_r^{\,2})}{\rho}\right] \tag{2}$$

$$\rho u\,\frac{\partial e}{\partial x} = -P\,\frac{\partial u}{\partial x} - \frac{\partial}{\partial x}\left[\frac{(1-\alpha)\alpha\rho_\ell\rho_g u_r(e_g - e_\ell)}{\rho}\right] - P\,\frac{\partial}{\partial x}\left[\frac{(1-\alpha)\alpha u_r(\rho_\ell - \rho_g)}{\rho}\right] + \frac{4H}{D_i}\,(T_{res} - T_w) \tag{3}$$

The above equations describe average fluid properties over the cross section and thus do not satisfy the no-slip boundary condition at the wall of the well. The slip is given as a function of flow regime. The limits of these regions (bubble, slug, transition and mist) that were used are defined in Orkiszewski (1967). Slip for these regions is discused in Orkiszewski, (1967) and Wallis (1969). The program uses an overall friction factor as described in Chisholm (1973). Empirical relations, correlating steam tables for the properties of water and wet steam are used in the program (Miller, 1978). These relations are accurate to within 5% of the steam table values.

MEASURED AND COMPUTED PRESSURES IN WELL M90

An attempt was made to calculate the pressures at various depths in the bore and then to compare them with those measured in the Cerro Prieto wells. Figure 1 shows the measured and computed pressures in well M-90 for the given wellhead conditions. The well is of uniform diameter. Calculated pressure profiles for two different wellhead pressures are shown in the figure. One of them is for the measured wellhead pressure of 37.4 kg/cm^2 gauge. The computed pressures are lower than those measured throughout the depth of the well with a maximum difference of about 11% at a depth of 1380 meters. The second calculated profile is for the wellhead pressure of 39.5 kg/cm^2-gauge which is obtained by extending the measured pressure profile to the surface. The maximum pressure difference in this case is only about 6%. It was observed from the computer output that a two-phase slug flow regime existed throughout the well and thus a drastic change in pressure gradient is not likely near the wellhead. In other words, one would expect a wellhead pressure of 39.5 kg/cm^2 gauge at the wellhead if the pressures measured in the well are correct. Or alternatively, if the measured wellhead pressure of 37.4 kg/cm^2 gauge is correct, then the measured downhole pressures should be in error. This shows that there exists a discrepancy between the pressures measured at the wellhead and those in the well. As in any other field work or experimentation, such discrepancies do arise as a direct result of human errors, instrumental errors or both. The computed and measured profiles for M-90 are in good agreement. However, it must be emphasized that even a 5% error in the calculation can lead to a large absolute error. For M-90, 5% error is about 70 psi. A comparison between the measured and computed pressures in the Cerro Prieto well M-51 was also made. It was found that computed pressures were within 6-7% of those measured in the well.

EFFECT OF HEAT LOSS AND OPEN INTERVAL ON COMPUTED DOWNHOLE PRESSURE

The effect of heat loss from the wellbore to the surroundings on the well pressure was also studied by considering that a linear temperature profile (assumed to approximate the natural geothermal gradient) exists in the reservoir at a distance (R_1) of 1 m and 5 m from the well. A hyperbolic profile was then fitted between the well and the geothermal gradient to obtain the temperature gradient at the well. It was found that the maximum pressure drop associated with heat loss for R_1 = 1 m was about 2.5% while negligibly small for R_1 = 5 m in well M-90. Thus, for all practical purposes, steady state heat transfer from Cerro Prieto production wells can be neglected. Gould (1974) also arrived at the same conclusion for high production wells. To study the effect of the thickness of open interval on the bottom hole pressures, we varied the thickness from 10 m to 160 m in the well M-90. It was found that an increase of only about 0.5% occurred in the bottom hole pressures for an open interval of 160 m. Thus, for all the cases discussed hereafter, we assume that the heat loss from the well is negligibly small, and that the depth of the open interval is equal to the distance between two nodes in the finite difference mesh.

EFFECTS OF WELLHEAD PARAMETERS

As noted, a possibility exists that the measured wellhead parameters such as pressure, mass flow rate, dryness fraction, enthalpy, etc., may be in error by a few percent. Thus, it seems appropriate to find the effect of such errors on the calculated downhole pressures in the well. We varied three important wellhead parameters (mass flow rate, pressure, and enthalpy) within ±20% of their measured value in well M-90 and calculated the change on the bottom hole pressures.

Table 1 shows bottom hole pressures (BHP) for different mass flow rates in well M-90. For a 20% increase in mass flow rate at the wellhead, the bottom hole pressure increased by about 6.5% the for a 20% decrease in flow rate there is about 5% decrease in BHP. The difference between wellhead and downhole pressure is not affected significantly by the mass flow rate. However, it maybe noted that the wellbore model is independent of the reservior.

Table 2 shows the effect of well head pressures (WHP) on the BHP in well M-90. It may be observed that a 20% increase in WHP results in an increase of about 25% in BHP while a 20% decrease in the WHP leads to about 18% decrease in BHP. The error in the WHP in this case shows up directly in the BHP.

Effect of enthalpy on BHP is shown in Table 3. It may be observed that an enthalpy increase of 20% reduces BHP by about 14% but a corresponding decrease leads to an increase of about 70% in BHP. An increase in enthalpy results in more steam and lighter fluid giving rise to lower pressures at the bottom of the well as shown in Table 3. BHP is not affected as much by an increase in enthalpy as it does by decreasing the same. This may be attributed to the fact that a decrease in the enthalpy results in a denser, heavier fluid giving rise to higher pressures at the bottom of the well. Effect of flowing dryness fraction at the wellhead on BHP was also studied. It was found that a variation in enthalpy affects the downhole pressures more than a corresponding change in the dryness fraction. The fluid enthalpies at Cerro Prieto wells are calculated by using dryness fraction and steam properties at the separator pressure. Thus, it is advisable to compute BHP by using dryness fraction rather than enthalpy to avoid the possibility of a compounding error.

EFFECTS OF WELLBORE DIAMETER AND SCALING

In addition to the measured wellhead data, the inside diameter of the well is needed to calculate the BHP. A study was done to find its effect on the calculated bottom hole pressures. Table 4 shows the calculated BHP in M-90 for various inside radii. The BHP was 41% more for 12 cm inside diameter and 150% more for 8 cm diameter compared to that for 16.3 cm diameter. Thus, in the 8 cm diameter case, a reduction of 76% in area leads to a much higher increase (150%) in the downhole pressure. This figure may be unrealistic since a large reduction in the area is assumed throughout the wellbore. In any event, it is clear that the effect of inside diameter on the BHP is considerable. Some Cerro Prieto wells do have large scale deposits. For example, well M-30, which, as of 1976, had scaling in excess of 60 mm at a depth of 1,500 meters. Similar scale deposits were also observed in many other wells in the field. Thus, to obtain reasonable values for downhole pressures, it is necessary to have a computer program which accounts for variations in the wellbore diameters. Using the control volume concept, the following equations of mass, momentum and energy were derived for a finite volume in which the diameter change occurred.

$$(\rho A u)_{\ell + g}\Big|_{\text{up}} = (\rho A u)_{\ell + g}\Big|_{\text{down}} \qquad (4)$$

$$\left.\left(PA_{av} - \rho A \frac{\Delta x}{2} g + \rho A u^2\right)_{\ell + g} - \frac{f\rho u^2 \pi D_i \Delta x}{16}\right|_{up}$$

$$= \left.\left(PA_{av} + \rho A \frac{\Delta x}{2} g + \rho A u^2\right)_{\ell + g} + \frac{f\rho u^2 \pi D_i \Delta x}{16}\right|_{down} \qquad (5)$$

$$\left.\left[\rho A u \left(e + \frac{u^2}{2}\right) + PAu\right]_{\ell + g}\right|_{up} = \left.\left[\rho A u \left(e + \frac{u^2}{2} + g\Delta x\right) + PAu\right]_{\ell + g}\right|_{down} \qquad (6)$$

In deriving the above equations, we have neglected energy dissipation due to friction and eddy losses. In these equations 'up' stands for the upstream side and 'down' for the downstream side. Subscript ℓ stands for liquid and g for steam. Given the conditions at point 'up', the parameters at point 'down' could be calculated. Figure 2 shows the computed and calculated pressures in the Cerro Prieto well M-91. The inside diameter of the well changes at a depth of about 1940 meters. It was found from the computer output that a two phase slug flow exists in the well above 900 metres and a single phase liquid water flows below 950m. A change in the pressure gradient at about 900-1000 m depth is noticed. It is clear from the figure that there is an excellent agreement between the measured and computed pressures. The percentage difference in BHP is less than 1%.

Well M-39 of Cerro Prieto field was also selected to show the effect of multiple inside casing diameters on downhole pressures (Figure 3). Production data for June 1976 was used to compute downhole pressures. Pressures calculated using the actual casing diameters are highest among all the cases shown. Pressure gradient between 1000 m to 1100 m depth change in response to changes in inside casing diameters. Higher pressure gradients below 1200 meters indicate single phase liquid flow. The computed pressures for the uniform inside diameters of 0.2012 m and 0.2736 m, as shown in Figure 3, are lower than those obtained using the actual diameters. In fact, bottom hole pressures decrease by 31.6% and 67.8% for the internal diameter of 0.2012 m and 0.2736 m, respectively. Pressures calculated assuming a uniform diameter of 0.177 m were very close to those computed using the actual casing diameter. This indicates that the gravity effect dominates the pressures more than the inertia effect when there is single phase liquid flow. Unfortunately, no data for measured downhole pressures were available to compare with these computed pressures. These results indicate that the computed downhole pressure may be significantly in error if actual inside casing diameters are not taken into account.

Figure 4 shows the effect of size and position of the scale deposits or of a liner of 200 m length on the pressure distributions in the Cerro Prieto well M-51. Pressures are larger for thicker scale deposits since one would require higher pressures to push the fluid through a small opening. A liner of small diameter set near the wellhead needs higher bottom hole pressure compared to the one set near the bottom of the well bore. This is due to the pressure propagation in the well bore. A similar profile was measured in test 11-3 of the well BR-11 where solid scale deposits up to 2 inches thick were found in the liner (Gould, 1974).

CONCLUSIONS

We have found that calculated downhole pressures are quite sensitive to measured well head conditions and well inside diameter data. The parameters to be measured, in order of decreasing accuracy, are well inside diameter, wellhead pressure, dryness fraction and mass flow rate. Based on the data presented we consider that LBL's computer program WELFLO calculates reasonable downhole conditions provided that accurate data is provided.

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NOMENCLATURE

$A_{up(down)}$ = inside area of the well at upstream (downstream) side, m^2
A_{av} = average area of the well = $(A_{up} + A_{down})/2$, m^2
D_i = inside diameter of the well, m
e = internal energy, of the steam-water mixture, J/kg
$e_{\ell(g)}$ = internal energy of water (steam), J/kg
f = coefficient of friction in the two-phase flow
g = gravitational acceleration, m/sec^2
H = film heat transfer coefficient in the well, $J/sec\text{-}m^2\text{-}°K$
P = pressure in the well at any cross section, Pascals
T_{res} = reservoir temperature, °K
T_w = well temperature, °K
u = mass averaged velocity in x-direction, m/sec
$u_{\ell(g)}$ = velocity of water (steam) in the well, m/sec
u_r = slip velocity = velocity of steam - velocity of water, m/sec
x = coordinate axis passing through the center of the well, upward positive, m
α = saturation of steam
Δx = interval between two nodes in the finite difference scheme, m
ρ = density of the steam-water mixture, Kg/m^3
$\rho_{\ell(g)}$ = density of water (steam) in the well, kg/m^3

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TABLE 1: Effect of mass flow rate on the bottom hole pressures (B.H.P.) in the Cerro Prieto well M-90

PERCENTAGE CHANGE	MASS FLOW RATE (Tonnes/hr)	B.H.P. (Kg/cm^2-g)	% DIFF B.H.P.
+20%	195.60	95.6146	+6.5
+15%	187.45	94.0685	+4.8
+10%	179.30	92.6014	+3.184
+ 5%	171.15	91.1352	+1.57
0%	163.00	89.7122	0
- 5%	154.85	88.3324	-1.52
-10%	146.70	86.996	-2.99
-15%	138.55	85.9179	-4.18
-20%	130.40	84.9890	-5.2

TABLE 2: Well head pressures and corresponding bottom hole pressures (B.H.P.) in the Cerro Prieto well M-90

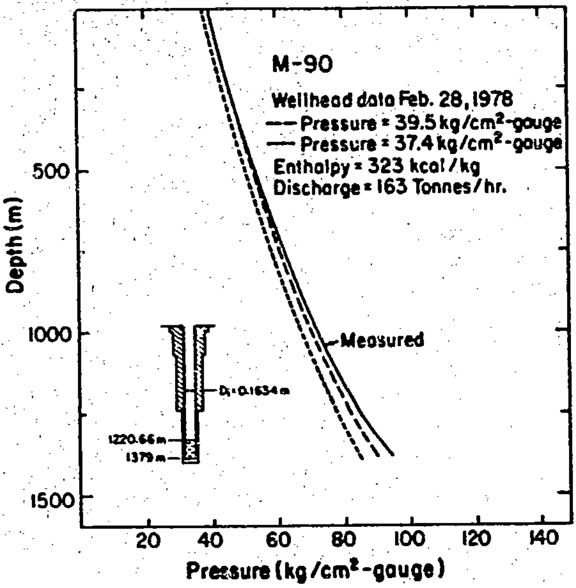
PERCENTAGE CHANGE	WELLHEAD PRESSURE (Kg/cm^2-g)	B.H.P. (Kg/cm^2-g)	% DIFF B.H.P.
+20%	47.40	112.776	+25.42
+15%	45.43	107.047	+19.10
+10%	43.45	101.205	+12.66
+ 5%	41.48	95.2621	+ 6.12
0%	39.5	89.7122	0%
- 5%	37.53	84.9074	- 5.29
-10%	35.55	80.6937	- 9.94
-15%	33.58	77.0025	-14.00
-20%	31.6	73.7173	-17.63

TABLE 3: Effect of well head enthalpy on the downhole pressures in the Cerro Prieto well M-90

PERCENTAGE CHANGE	ENTHALPY (Kcal/kg)	B.H.P. (Kg/cm^2-g)	% DIFF B.H.P.
+20%	387.60	77.1392	-13.85
+10%	355.30	77.6372	-13.31
+ 5%	339.15	80.4552	-10.20
0%	323.00	89.7122	0
- 5%	306.85	111.342	+23.83
-10%	290.70	131.156	+45.67
-15%	274.55	146.203	+62.252
-20%	258.40	153.316	+70.09

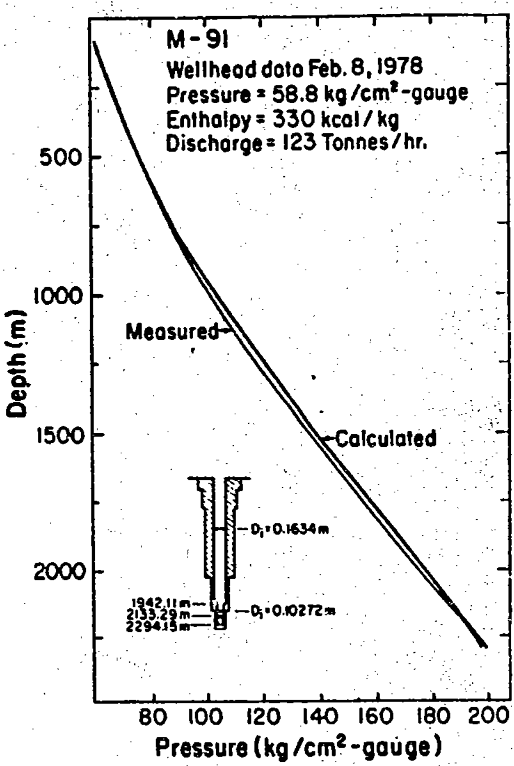
TABLE 4: Effect of well inside diameter on the bottom hole pressures in the Cerro Prieto well M-90

INSIDE RADIUS (m)	AREA (m^2)	% AREA CHANGE (m^2)	B.H.P. (Kg/cm^2-gauge)	% DIFF B.H.P.
0.08172	2.098×10^{-2}	0	89.7122	0
0.06	1.13097×10^{-2}	-46.1	127.071	41.17
0.04	5.0265×10^{-3}	-76.04	225.592	149.74



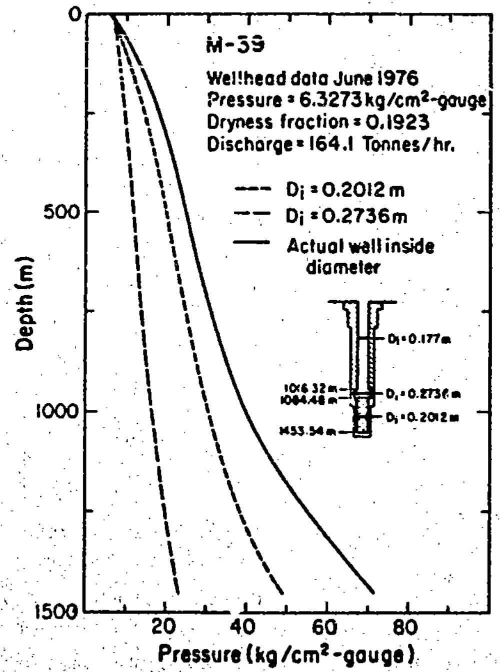
XBL 8012-6577

Figure 1. Measured and calculated pressures in the Cerro Prieto well M-90.



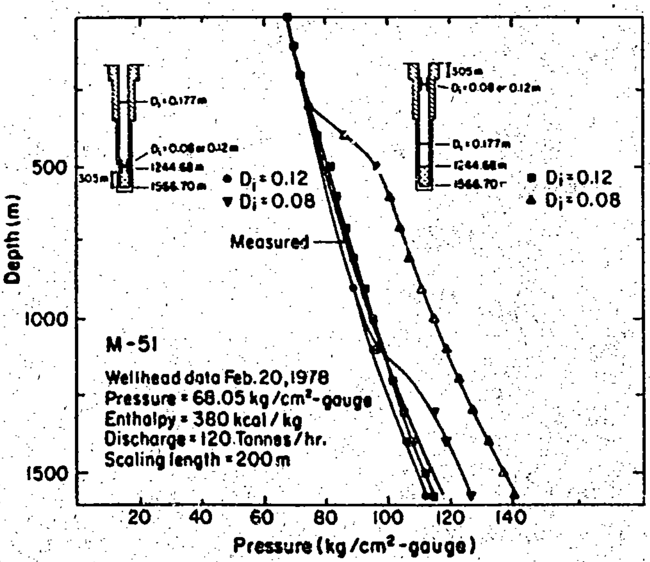
XBL 8012-6576

Figure 2. Computed and measured pressures in the Cerro Prieto well M-91.



XBL 811-2518

Figure 3. Effect of inside diameter on the calculated pressures for the Cerro Prieto well M-39.



XBL 8012-6578

Figure 4. Effect of size and location of scale deposits on the pressures in the well.