PROCEEDINGS, Twelfth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 20-22, 1987
SGP-TR-109

PRESSURE BUILDUP TESTING OF WELL 18 IN LOS AZUFRES FIELD, MÉXICO

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INTRODUCTION

Well 18 is a production well in the southern zone of Los Azufres geothermal field in México (see Figure 1). The well is located on the eastern flank of the drilled area, and produces a steam/water mixture from a depth of 1200-1250 m. A 19 hour pressure buildup test that was carried out in March 1986, is the subject of this paper. It is a part of work reported by Sánchez-U. (1986) at the Geothermal Training Programme in Iceland.

WELLS AND FIELD

Since 1972, 47 wells have been drilled in Los Azufres field: 27 producers, 8 injectors, and 12 exploration (Reyes-S., 1985). The wells in the southern Tejamaniles zone produce higher enthalpy fluids than wells in the northern Maritaro zone: 2485 kJ/kg and 1915 kJ/kg, respectively. The total flowrates of the production wells are reported 1500 tonne/hour in the southern zone and 1419 tonne/-hour in the northern zone.

The explored surface area of the Los Azufes geothermal field is 32 km² (Molinar-C., 1985). The reservoir can be described as saddle-shaped, with a dome-like structures extending to the surface in the southern Tejamaniles zone and the northern Maritaro zone. The thermodynamic state of the reservoir fluid has been investigated by Iglesias et al. (1985). In the main, the subsurface temperature follows the boiling-point-for-depth curve, except in the upper part of the southern zone, where the pressure profile indicates vapor-dominated conditions. Such reservoir conditions are discussed by Gudmundsson (1986a), for example.

The Los Azufres reservoir has been exploited since 1972 (Hiriart-L., 1983; Ortega-P. 1985) using 5 non-condensing 5 MW units, in total 25 MW. The inlet steam pressure of these units is about 8 bar-a and the steam flowrate 60 tonne/hour. A 50 MW central power plant is under construction in the Tejamaniles zone - there are plans to add 7 more non-condensing units (Alonso-E., 1985). Well 18 is scheduled to supply steam to one of these non-condensing units. The well is 1328 m deep and completed 13-3/8" to 300 m, 9-5/8" to 1000 m, and 7" from 959 m to bottom, the slotted section starting at 1013 m depth. This completion is typical in Los Azufres.

MEASUREMENTS

A temperature log from June 1983, shows the subsurface temperature profile to be rather flat, increasing from 251°C at 100 m depth to 266°C at 1000 m, reaching a maximum temperature of 268°C at 1200 m depth. The well was output tested in March, 1986, where the mass flowrate and mixture enthalpy were measured at four settings. These measurements are shown in Figure 2. A maximum flowrate of 43 kg/s was measured at a wellhead pressure of 9 bar-a and mixture enthalpy of 1763 kJ/kg. The well was then shut in and kept that way for several days.

On March 17, 1986, well 18 was opened and discharged for two days (52 hours), which is typically the time required for Los Azufres wells to reach stable flowing conditions. The mass flowrate and mixture enthalpy were measured 16.2 kg/s and 1314 kJ/kg, respectively, using the lip pressure and weir method, at a wellhead pressure of 32 bar-a. At this setting, the well discharged at a relatively low flowrate and enthalpy.

An enthalpy of 1314 kJ/kg corresponds to liquid water just below 295°C. This temperature is considerably above the maximum of 268°C measured

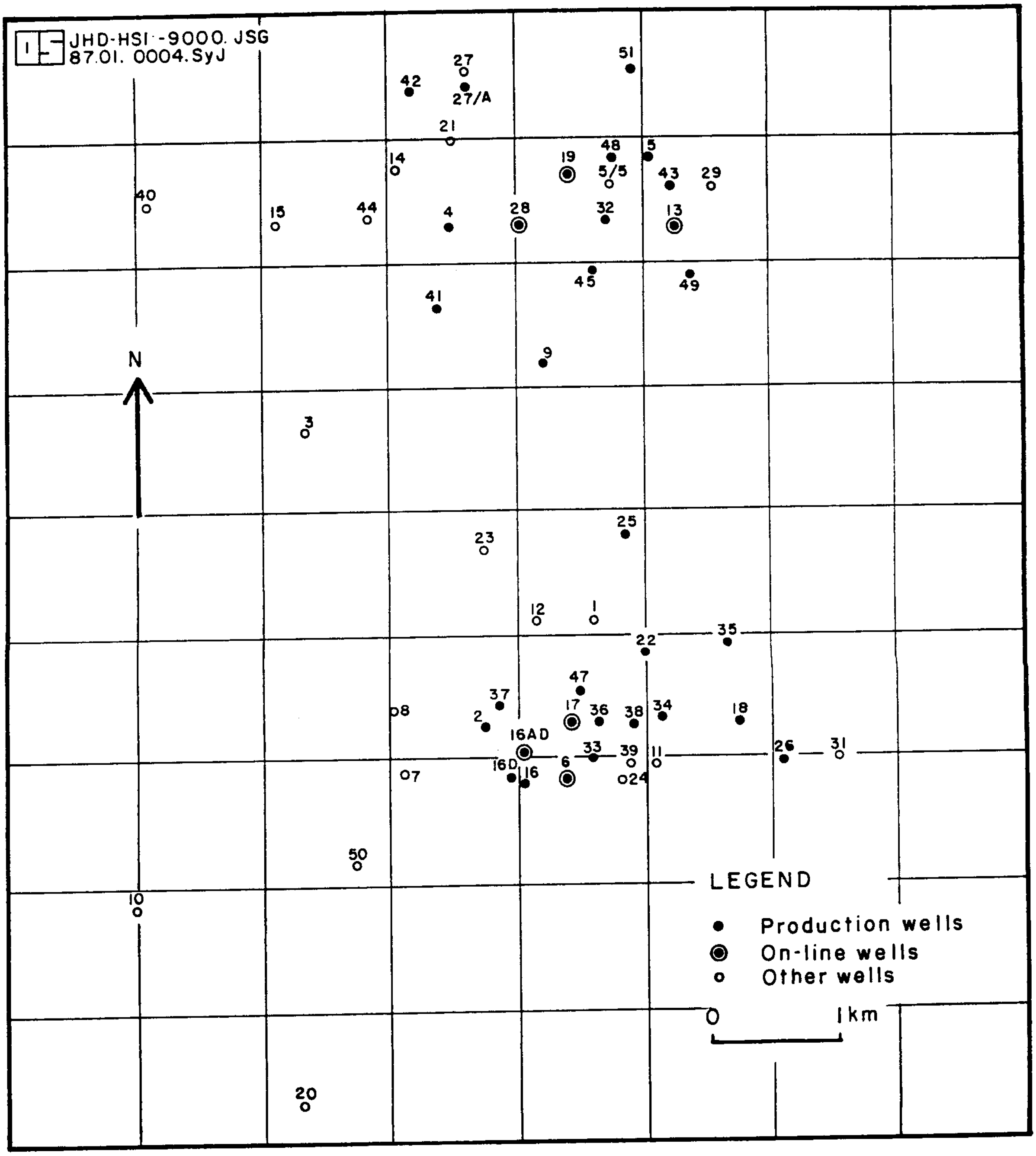

Figure 1 - Los Azufres field map.

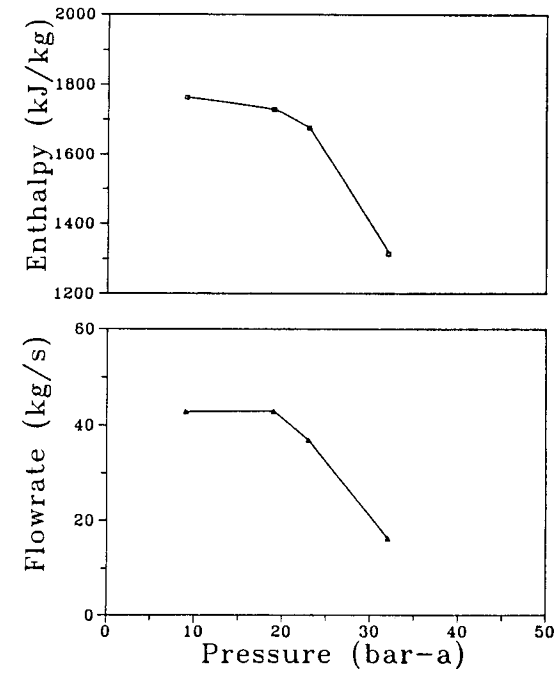

Figure 2 - Output curve well 18.

in the well three years earlier, in June 1983. It means that a two-phase steam/water mixture enters the well at typical flowing conditions - the well has excess enthalpy. This general behavior is discussed by Gudmundsson (1986b), for example. It is of interest that Iglesias et al. (1985) report that the liquid-dominated part of Los Azufres has an average enthalpy of 1317 kJ/kg - this is the liquid below the steam cap in the southern zone. Of interest also is that measured downhole temperatures in Los Azufres wells are consistently below the values determined by geothermometers (Nieva et al., 1983). For example, the downhole temperature in well 18 was measured 250°C in 1982, while silica indicated 266°C and sodium-potassium-calcium 290°C.

BUILDUP DATA

Before the well was shut in, temperature and pressure elements (Kuster) were lowered to 1200 m depth. The main feed zone of the well is located in the interval 1200-1250 m. Pressure buildup and temperature were recorded for 19 hours after shut-in. These data are shown in Table 1. The temperature increased quickly from 263°C to 265°C. The Cartesian plot of the pressure data are shown in Figure 3, showing that the wellbore was liquid-filled during the buildup

TABLE 1. Pressure and temperature buildup.

dt (h)	Press. (MPa)	Temp. (C)	$\frac{t+dt}{dt}$	dp (MPa)
0.000	5.135	263		0.000
0.100	5.271	264	531.000	0.136
0.133	5.282	264	398.000	0.147
0.167	5.295	264	319.000	0.160
0.200	5.299	-	266.000	0.164
0.233	5.303	-	228.143	0.168
0.267	5.307	-	199.750	0.172
0.300	5.312	-	177.667	0.177
0.333	5.316	-	160.000	0.181
0.417	5.320	-	128.200	0.185
0.500	5.323	-	107.000	0.188
0.667	5.327	-	80.500	0.192
0.833	5.332	-	64.600	0.197
1.000	5.327	264	54.000	0.192
1.333	5.323	-	40.750	0.188
1.667	5.323	-	32.800	0.188
2.000	5.320	264	27.500	0.185
2.333	5.316	-	23.714	0.181
2.667	5.316	-	20.875	0.181
3.000	5.316	264	18.667	0.181
3.667	5.320	-	15.455	0.185
4.333	5.323	264	13.231	0.188
5.000	5.327	264	11.600	0.192
6.000	5.332	264	9.833	0.187
7.000	5.336	-	8.571	0.201
8.000	5.340	-	7.625	0.205
9.000	5.344	264	6.889	0.209
10.000	5.352	-	6.300	0.217
11.000	5.361	264	5.818	0.226
12.000	5.369	-	5.417	0.234
13.000	5.381	264	5.077	0.246
14.000	5.393	-	4.786	0.258
15.000	5.406	264	4.533	0.271
17.000	5.422	264	4.118	0.287
19.000	5.438	264	3.789	0.303

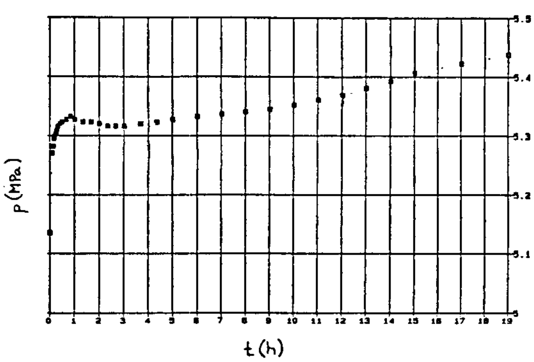

Figure 3 - Cartesian plot.

test. The pressure increased about 2 bar the first hours, and then decreased about 0.2 bar the next two hours, and then increased gradually 1.2 bar by the end of the 19 hour test. The 0.2 bar pressure decrease cannot be explained readily. It may be an artifact of the two-phase nature of the reservoir-wellbore system; it may result from wellbore storage or perhaps interzonal flow.

Flashing in the formation, as indicated by the above data, makes it difficult to apply traditional pressure transient analysis techniques, as discussed by Gulati (1975) and Gringarten (1978), for example. However, this is reported less of a problem in buildup than drawdown tests (Gringarten, 1978). In the present buildup test, it was assumed that the two-phase zone around the wellbore had not developed much during the 52 hour flowing period. That the well was liquid-filled during the buildup test, as shown by the simultaneous temperature and pressure logs at 1200 m depth, supports this assumption.

INTERPRETATION

The methodology of pressure transient data interpretation, as presented by Gringarten (1985), guided most of the present work. Furthermore, the interpretation was carried out in the spirit that "many different conditions can cause the same or similar well-test response," as pointed out by Earlougher (1977, p.123). Therefore, the interpretation presented here is one possible interpretation of the data.

Several diagnostic (log-log) and specialized (log-linear) plots were made of delta-pressure and its derivative with respect to time, some of which will now be presented. The diagnostic plot in Figure 4 shows an inner boundary with a slope between one-half and one-quarter, which indicates a single medium conductivity fracture. Also in Figure 4, there are two straight lines of the same slope evident in the infinite acting period. This behavior is typical of double-porosity reservoirs.

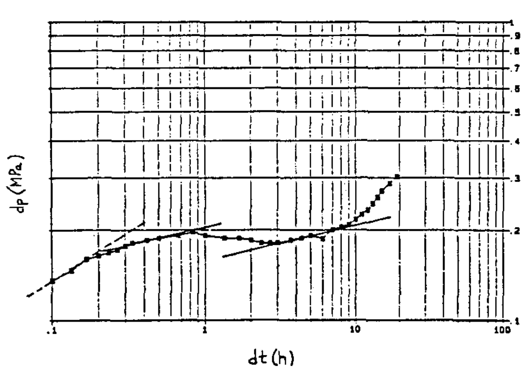

Figure 4 - Diagnostic plot.

At late time, the pressure begins to increase faster, which is characteristic of an outer boundary. A specialized plot was constructed to investigate this further, see Figure 5.

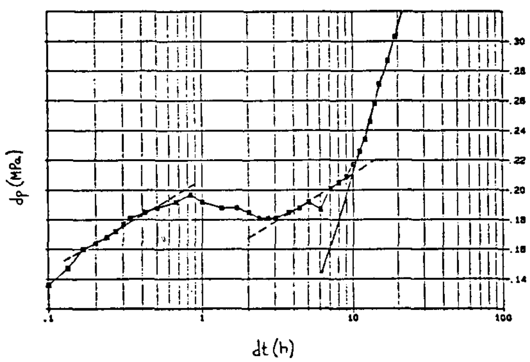

Figure 5 - Specialized plot.

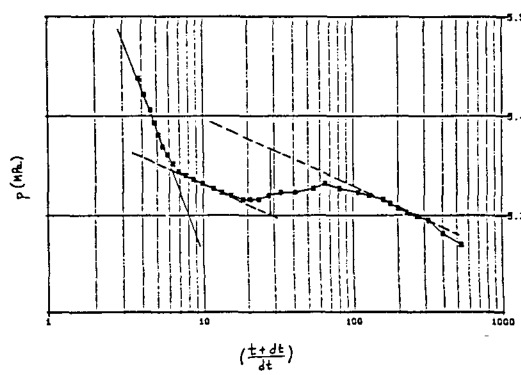

Figure 6 - Horner plot.

The slope of the late time straight line is about four times that of the total system reservoir slope. This sharp increase in pressure, indicates the existence of some boundary other than a single fault - perhaps that the drainage volume of the well is between two (intersecting) faults.

A Horner plot of the buildup data is shown in Figure 6. An extrapolation of the late time data to when dt >> t, indicates an average reservoir pressure at 1200 m depth as 5.7 MPa (57 bar-a). The slope, m, of the two parallel stratight lines was found from

$$m = 0.1832\ (wv\mu/kh) = 0.0713$$

where w is the mass flowrate and v the specific volume in S.I. units. This slope gives the following permeability-thickness product

$$kh \approx 5.4\times10^{-12}\ m^3 = 18{,}000\ \text{md-ft}$$

These values were calculated for liquid water at 265°C with specific volume $v = 1.287\times10^{-3}$ (m^3/kg) and viscosity $\mu = 1.0\times10^{-4}$ (Pa.s). For an assumed porosity of ϕ = 0.1, a total compressibility of c = 1.9x10^{-9} Pa^{-1} and a reservoir thickness h = 50 m, the skin value was estimated

$$s = -5.3$$

The pressure increment, δp, between the two parallel straight lines on the Horner plot in Figure 6, can be used to evaluate Ω, the ratio of the storativity of the fissure system to the storativity of the total fissure-matrix system (Gringarten, 1985). The pressure increment read from Figure 6 was 0.07156 MPa, giving

$$\Omega = 10^{-\delta p/m} = 0.10$$

DISCUSSION

Results from six pressure transient tests on four wells in Los Azufres field have been reported by Nieva et al. (1985). The analyses were carried out using double-porosity type curves. It was found that the "fracture permeability" varied from 1-25 md, while the "matrix permeability" varied from 0.003-5 µd. It was further stated that these latter values were consistent with measurements on cores. The "storage ratio" of the double-porosity system was reported 0.01 by the same authors.

The permeability-thickness product determined in the present buildup test, 5.4 dm, corresponds to about 100 md if the reservoir thickness, h, is assumed 50 m. Clearly, this value is much greater than the values reported by Nieva et al. (1985): 4-100 greater than the "fracture permeability." Similarly, the storativity ratio determined in the present test was an order of magnitute larger than that reported by Nieva et al. (1985).

The great difference between the results of the present work and that reported by Nieva et al. (1985), needs to be clarified. The permeability-thickness product reported in this paper for Los Azufres well 18, appears to fall within what is reasonable for typical geothermal wells, while the storativity ratio from both studies appear satisfactory. The fact that Nieva et al. (1985) found their field test values to be consistent with core data, suggests that the permeability-thickness product reported in the present work, may be more representative - permeability values derived from geothermal well tests are generally higher than laboratory values on cores from the same wells.

Well 18 was discharged for about two days at a high wellhead pressure and a low flowrate - the mixture enthalpy of the well was at its lowest value. However, this enthalpy was higher than that of liquid water at the highest temperature measured downhole, but similar to the water in the liquid part of the overall reservoir. During the subsequent 19 hour buildup period, the wellbore was liquid-filled at depth of 1200 m, where the pressure and temperature were measured with time - the main feed zone of the well is in the range 1200-1250 m depth . The pressure buildup data, therefore, were analysed assuming all-liquid conditions. The first few hours of pressure buildup may have been complicated by condensation phenomena.

CONCLUSIONS

The permeability-thickness product of well 18 in Los Azufres field was determined 5.4 dm from a Horner plot. The well was found to be intersected by a fracture, as evident from the slope on a log-log plot at early time, and a skin value of -5.3. The overall pressure buildup of the well was found to be typical for double-porosity reservoir behavior, having a storativity ratio of 0.1. An outer boundary behavior was observed in the pressure buildup data.

ACKNOWLEDGEMENTS

The first author would like to thank the Comisión Federal de Electricidad for the permission to attend the Geothermal Training Programme in Iceland, and the United Nations University for providing the fellowship that made it possible.

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