USE OF OBSERVATION WELL DATA IN DETERMINING OPTIMUM WELL SPACING AND RECHARGE IN A GEOTHERMAL FIELD (CERRO PRIETO)

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ABSTRACT

Change of standing water level or pressure in an observation well within the drainage area of an exploited field can be analyzed to give an important well parameter which relates recharge, storativity, and total field drainage area. This parameter then can be used to determine the optimum well spacing within the field, assuming that the production rate and enthalpy do not change appreciably during the foreseen economic life of the field, and that the field can be considered approximately isotropic and "pseudo-porous." An example of this application is given using the data of the Cerro Prieto Geothermal Field, Baja California, Mexico, between May 1974 and March 1977. Although one expects changes in both enthalpy and production rate in years to come (usually a decline in production rate and an increase in enthalpy), the figures obtained may serve as first approximations of guidelines for the field development.

INTRODUCTION AND THEORY

The pressure drop at a well at the center of a bounded drainage area during semisteady (pseudosteady) conditions is given by:

$$p_D = 2\pi t_{DA} + \frac{1}{2}\,\ell n\left(\frac{A}{r_w^2}\right) + \frac{1}{2}\,\ell n\left(\frac{2.2458}{C_A}\right) + s \qquad (1)$$

Where $\frac{1}{2}\,\ell n\, C_A$ is a shape factor (its values can be found in Table C.1 in ref. 1). It will be noted that for many drainage shapes it is negative and has its maximum value for a circle, indicating that for the same production rate, pressure drop at the center of a circular drainage area is less than the other shapes. The circular shape is closely followed by a hexagon and then a square. However, in a field, if the production wells are drilled in a regular square grid, for the same drainage area, one gets a slightly smaller spacing than the hexagon configuration along the main grid lines with a slightly better evening-out of pressure distribution. Therefore, in a geothermal field which can be considered approximately isotropic and pseudo-porous and at semisteady state during production, a regular square-grid production well pattern can be considered convenient.

Equation 1 takes the following form for a well at the center of a square drainage area if one uses the metric units:

$$\Delta p_{r_w} = \frac{Wvrt}{A\phi hc_t} + mr\left[\log\frac{A}{r_w^2} - 1.1382 + \frac{s}{1.151}\right] \tag{2}$$

where $A = d^2$

If one now assumes that as the pressure declines within the drainage volume, recharge comes into it, at semisteady-state conditions, the rate of decrease of pressure would be:

$$\frac{\alpha \dot{W} vr}{A\phi hc_t}$$

where α would indicate the fraction of the production coming from the storage within the drainage volume. The difference between the bounded-reservoir rate of decrease of pressure and recharged reservoir rate of decrease of pressure would be caused by the recharge which would be supplying a fraction of $(1-\alpha)$ of the production. Therefore, when the recharge into the drainage area is taken into account, Eq. 2 becomes:

$$\Delta p_{r_w} = \frac{\alpha Wvrt}{A\phi hc_t} + mr\left[\log\frac{A}{r_w^2} - 1.1382 + \frac{s}{1.151}\right] \tag{3}$$

Therefore, in a producing geothermal field of the above description, if the temperature of the recharge water does not diminish with time, the maximum allowable pressure drop at the well bottom, with a reasonably constant production rate, would determine the production life of each well. However, during the life time of a well, production rate usually diminishes with time, but, on the other hand, enthalpy usually goes up, hence more or less maintaining the power output constant. If this happens, the pressure drop per kilowatt hour generated would go down with time, and the well's economic life would increase, becoming greater than the one calculated, assuming constant enthalpy and production rate. Therefore, if one assumes a constant production rate to calculate a well's economic production life, one errs on the safe side.

Then, if the average production rate of each well and the maximum allowable pressure drop are specified, by using Eq. 3, one can calculate the economic production life of the wells for a fixed drainage area or the optimum drainage area of each well (therefore, the well spacing) for a predetermined economic life. Equation 2 can be written:

$$\frac{\Delta p_{r_w}}{W} = \frac{\alpha vrt}{d^2\phi hc_t} + \frac{mr}{W}\left[\log\frac{d^2}{r_w^2} - 1.1382 + \frac{s}{1.151}\right] \tag{4}$$

$$\frac{\Delta p_w}{W} = \frac{A_T\ vrt}{d^2 A_T \phi h c_t} + \frac{mr}{W} \left(\log \frac{d^2}{r^2 w} - 1.1382 + \frac{s}{1.151} \right) \tag{5}$$

But,

$$\frac{\alpha vr}{A_T \phi h c_t} = E$$

a parameter of the field under semisteady-state conditions, and can be determined by observing the pressure or water level decline in observation wells.[2]

Then,

$$\frac{\Delta p_w}{W} = \frac{A_T Et}{d^2} + \frac{mr}{W} \left(\log \frac{d^2}{r^2 w} - 1.1382 + \frac{s}{1.151} \right) \tag{6}$$

Knowing A_T, this equation can be solved for d, the optimum well spacing.

Further, if the skin effects of the wells are negligible, which is usually the case with normal producing wells, Eq. 6 becomes:

$$\frac{\Delta p_w}{W} - \frac{A_T Et}{d^2} = \frac{mr}{W} \left(\log d^2 - (1.1382 + \log r^2 w) \right) \tag{7}$$

Normally, $\frac{mr}{W} \log d^2$ is smaller than the linear pressure drop, and it does not vary much between d = 100 and d = 500 m (which may be considered the general range of the well spacing), as can be seen below:

d (m)	A (m^2)	log A
100	10^4	4.00
200	$4x10^4$	4.60
300	$9x10^4$	4.95
400	$16x10^4$	5.20
500	$25x10^4$	5.40

By considering an average value (4.70), one induces an error of $\pm$15%. If, however, one considers a range of 200 - 500 m (i.e., $\log d^2 = 5$), the error becomes $\pm$8%. In doing this, the expression within the bracket has a constant value, and Eq. 7 can be solved for A_T, i.e., n, the number of wells. Then, knowing d^2, the power capacity of each well under the production conditions assumed, approximate total power generation capacity of the field can be calculated without knowing A_T.

This is, of course, a result of the fact that as long as mr is small, i.e., a high permeability field, general field pressure decline is controlled by semisteady pressure drop, which is directly proportional to well production rate and the number of the producing wells. Also, by fixing E, one also takes into account the effect of A_T or its relationship with other factors, such as α and ϕhc_t.

APPLICATION

The conclusions reached in the previous section are illustrated by using the data from Cerro Prieto Geothermal Field, Baja California, Mexico. In ref. 2, the value of E was obtained by using the production data of the field between May 1974 and March 1977, and the standing water level decline in two observation wells, M-6 and M-10.

Figure 1 shows the configuration of the wells as of March 1978 in the Cerro Prieto Geothermal Field.

Cerro Prieto Geothermal Field is located within the Mexicali Valley, in an area of hot springs, approximately 35 kilometers south of Mexicali, Baja California. The reservoir consists of a series of sandstones, siltstones, and shales composing part of the Colorado River delta. In the western part of the field (to the west of the railroad), wells were drilled to about 1,400 m average, encountering the reservoir at an average depth of about 1,000 to 1,200 m, with maximum temperatures in the wells varying between 230 to 310°C. The wells drilled later, to the east of the railroad (along which runs the Cerro Prieto fault) found the reservoir at deeper levels (1,400 to 2,000 m) and with higher temperatures (up to 350°C). The water is highly charged with chemicals, with the total dissolved solids content reaching about 2%.

From ref. 2, $E = 0.0538 \times 10^6$ kg/cm^2/t. The value of $\frac{mr}{W}$ can be obtained from published data, as follows:

$\frac{mr}{W}$ (kg/cm^2/log~/t)	Reference	Remarks
0.034	(3.4)	Two-rate test, M-21-A
0.024	(4)	Interference test between M-50, 51, 90, and 91, and M-101

The allowable pressure drop can be assumed about 66 kg/cm^2, leaving the allowable well bottom pressure at about 20 kg/cm^2, which should be sufficient to produce with a wellhead pressure about 7 kg/cm^2 and overcome the frictional and other pressure losses.

The average well in the western part of Cerro Prieto field produces about 140 tons/hour and has a generation capacity of 5 MW (e).

Then:

$$\frac{\Delta p}{W} = 0.471 \text{ kg/cm}^2/t$$

Taking t = 20 years = 20 x 8000 hours:

$$r_w = 0.08 \text{ m}$$

$$\frac{mr}{W} = 0.024 \text{ kg/cm}^2/\log\text{~}/t$$

(assuming this value is more representative of the field), and using Eq. 7:

$$0.471 = \frac{A_T}{d^2}(0.861 \times 10^{-2}) + 0.024 (\log d^2 + 1.056) \qquad (8)$$

If one assumes different values for A_T and d, the right-hand side of Eq. 8 can be calculated and plotted as in Fig. 2. Then, for each A_T, the optimum well distance and the number of wells can be determined, as shown in Fig. 2.

It will be noted that, no matter what A_T is, the optimum well number is between 37 and 39. Taking the average well number, n = 38, the field capacity can be calculated as about 190 MW.

Also, it can be seen that, when $\log d^2 = 5$ is assumed in solving Eq. 8, $A_T/d^2 = n = 38$ is obtained, indicating that as long as the wells are kept 200 to 500 m apart, the general results would not change.

DISCUSSION

As pointed out before, the above results do not take into account change of well production and enthalpy with time. If the usual trend of increase in enthalpy with production is taken into account, more wells with smaller distances can be tolerated.

Moreover, in the eastern side of the field, the production is from deeper levels. This would increase the allowable pressure drop by about 50%. If the same E value is assumed, for $A_T = 10$ km^2, one would expect a distance of about 400 m, giving in total about 62 wells. For the same total area to the west of the railroad, the spacing would be about 520 m, giving 37 wells.

If, however, the eastern and western sides of the field are hydraulically and freely connected (i.e., the Cerro Prieto fault does not form a hydraulic barrier), then a total area of 20 km^2 (10 km^2 to the west and 10 km^2 to the east of the fault) would mean about 19 producing wells on the western and 31 producing wells on the eastern side, with distances of about 725 m and 565 m respectively. This would mean a minimum 50 wells providing a capacity of at least 350 MW (e). (The wells at the eastern part would have at least 8.25 MW (e) per well.)

CONCLUSIONS

The parameter obtained by relating standing water level or pressure in an observation well to cumulative discharge can be used in calculating the optimum well spacing and field capacity, assuming constant enthalpy and production rate during the field's economic life. In fields where the enthalpy and production rate change quickly (especially if the fields would tend to evolve rapidly to drier production), the method would not give realistic results.

NOMENCLATURE

p_D = dimensionless pressure (as defined in ref. 1)

t_{DA} = dimensionless time (as defined in ref. 1)

C_A = shape factor (ref. 1, Table C.1)

A = drainage area, m^2

A_T = total drainage area, m^2

r_w = well radius, m

s = skin effect

$\Delta p_{re} = p_o - p_{wr}$ = pressure drop at well, kg/cm^2

p_o = initial reservoir pressure

p_{wr} = pressure at reference level at production zone, kg/cm^2

W = well production rate, tons/hour

vr = specific volume at reservoir conditions, m^3/t

$$mr = \frac{0.526\ Wvr\mu}{kh}$$

μ = viscosity, centipoise

k = absolute permeability, darcies

h = effective production thickness, m

ϕ = effective porosity

c_t = total isothermal compressibility, $(kg/cm^2)-1$

α = fraction of production coming from drainage volume

t = production time, hours

$$E = \frac{\alpha vr}{A_T \phi h c_t}$$

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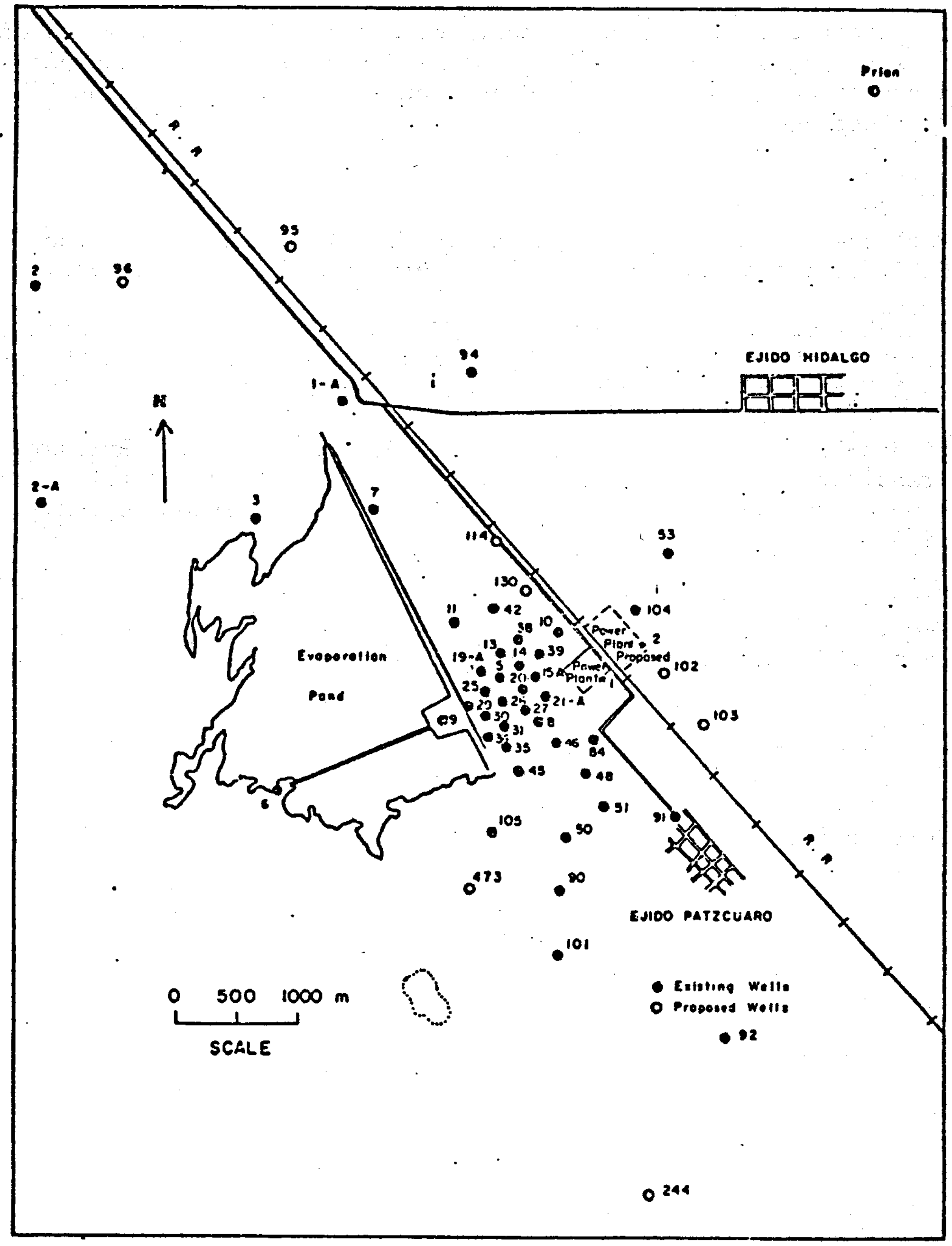

Fig. 1 Cerro Prieto geothermal field well locations (as of March 1978).

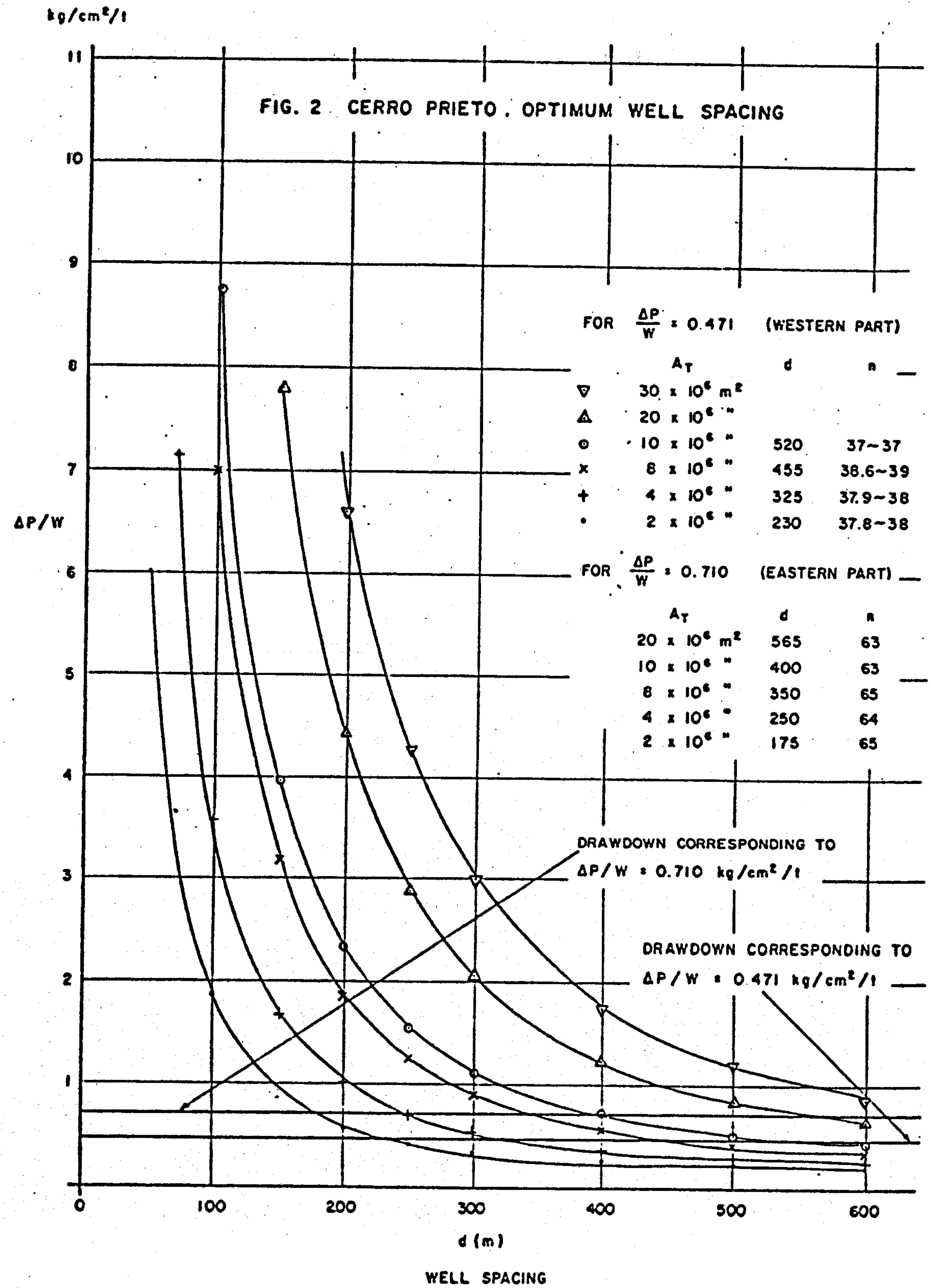

FIG. 2 CERRO PRIETO. OPTIMUM WELL SPACING