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INFLOW PERFORMANCE RELATIONSHIPS FOR GEOPRESSURED GEOTHERMAL WELLS

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ABSTRACT

This paper presents methods and results of predicting geothermal well performance using actual flow test data taken from a typical geopressured geothermal well. DOW/DOE L.R. Sweezy No. 1 Well was used for the flow rate predictions. Using the method of either Jones (1976) or Fetkovich (1973), this study shows that the productivity index of geothermal wells changes not only with flow rate but also with time.

INTRODUCTION

Three reservoir factors, fluid temperature, production rate per well and size of the reservoir, are most important to the commercial development of geothermal resources. If the fluid temperature and production rate per well are given, then the gross power generation per well and the number of wells required for a desired power plant or heating process can be estimated.

The cost of development and operation of a geothermal resource is largely dependent on the number of wells to be drilled and operated. Therefore, an estimate of the productivity of a single well is necessary to determine whether the development and operation of a geothermal field is economically feasible. Thus, there is a need for accurate prediction of flow rates for geothermal wells.

In earlier studies conducted by Gudmundsson[1] and Ortiz[2], the productivity index (PI), was assumed to be constant not only with flow rate but also with time. The PI is the ratio of the production rate, to the pressure drawdown at the producing interval.

In oil well production practice, it is commonly assumed that the PI is constant for a wide range of flow rates which for most oil wells are less than 500 STB/day. However, the brine production of geothermal wells is generally 100 to 200 times greater than that of oil wells. A typical geopressured geothermal well in the Gulf Coast area can produce as much as 100,000 barrels per day of hot water at a well head pressure in excess of 2,000 psig for a considerable period of time.[3]

The PI of geothermal wells is not a constant primarily because of the effects of turbulence caused by high flow rates. Also, the depletion of reservoir pressure will cause the PI to decrease. Vogel[4] suggested that the inflow performance relationships (IPR) curve can be used to provide more accurate flow rate predictions than can be estimated with constant PI methods.

THEORY

This study presents two methods for predicting present and future production performance of geothermal wells. These methods will provide engineers the ability to predict geothermal flow rates with high accuracy.

Method A: <u>Jones, Blount and Glaze Method</u>

The Jones, et al.,[5] method has been successfully applied in both oil and gas flow rates prediction problems. The method can also be used for predicting production performance for geothermal wells because it considers turbulent flow effects on the well's productivity.

The Jones' method uses flow test data to determine a well's flow capacity. Data are required from either two or more stabilized flow tests or from two or more isochronal flow tests. In either case, flow rates and flowing bottomhole pressures must be either measured or calculated.

Jones, et al.,[5] suggested that flow rate and pressure drawdown can be related and written as:

$$p_r - p_{wf} = Cq + Dq^2 \tag{1}$$

where: q = flow rate in STB/day
C = laminar flow coefficient
D = turbulence coefficient

From Eq. 1, it is apparent that a plot of $(p_r - p_{wf})/q$ vs. q has a slope of D, and an intercept of $C = \Delta p/q$, as q approaches zero.

Eq. 1 can be rearranged as:

$$PI = (C + Dq)^{-1} \tag{2}$$

With values of C and D given, the PI value of the well can be calculated for any flow rates. Eq. 3 shows that the PI is a dependent of flow rate, as the flow rate increases, the PI decreases.

Method B: Fetkovich's Method

Fetkovich[6] suggested that gas wells and oil wells behave quite similarly and could be analyzed using the same flow equation:

$$q_o = Jo' \, (p_r^2 - p_{wf}^2)^n \qquad (3)$$

This equation will result in a straight line with a slope of 1/n on a plot of log q_o vs. log $(p_r^2 - p_{wf}^2)$. Eq. 3 considers the effects of high flow rate through the inclusion of exponent n. Generally, the value of n ranges from 0.568 to 1.0.

As indicated earlier, the PI also changes with time; as the reservoir pressure decreases the PI decreases. Fetkovich used the following equation for future flow rate calculations:

$$q_o = Jo_i' \left(\frac{p_r}{p_{ri}}\right) (p_r^2 - p_{wf}^2)^n \qquad (4)$$

where Jo_i' is the initial productivity index at conditions of initial reservoir pressure.

EXAMPLE

In this study, actual flow test data from DOW/DOE L.R. Sweezy No. 1 Well[7] was used to predict flow rates using both method A and B mentioned above. L.R. Sweezy No. 1 is a geopressured geothermal well located in Vermilion Parish, Louisiana. This well was completed with a 5-1/2 inch production tubing and a 7-5/8 inch casing. The producing intervals were perforated at 13,349-13,388 ft. and at 13,395-14,406 ft. A downhole temperature of 237°F was measured at a depth of 13,395 ft., and the initial reservoir pressure at 13,395 ft. was 11,410 psia.

In order to determine the production performance of the geopressure reservoir, this well was subjected to a series of short term flow tests. However, test data from the first two flow tests were not reliable enough for analysis. Flow test results from flow tests 3, 4, and 5 are given in Table 1.

TABLE 1. Flow Test Data on L.R. Sweezy No. 1 Well

Flow Test No.	Average Flow Rate (STB/day)	Pressure Drawdown (psi)
3	6,455	380
4	8,615	560
5	10,977	820

Method A: Jones, et al., method

Based on the flow test data listed in Table 1, well performance data are given in Table 2 and the results are plotted on Figure 1. It is interesting to note that the values of Δp/q plotted against q define a straight line.

TABLE 2.
Performance Data for L.R. Sweezy No. 1 Well

Flow Rate (STB/day)	Pressure Drawdown (psi)	Δp/q (psi/STB/day)	PI (STB/day/psi)
6,455	360	0.056	17.8
8,615	560	0.065	15.4
10,977	820	0.075	13.3

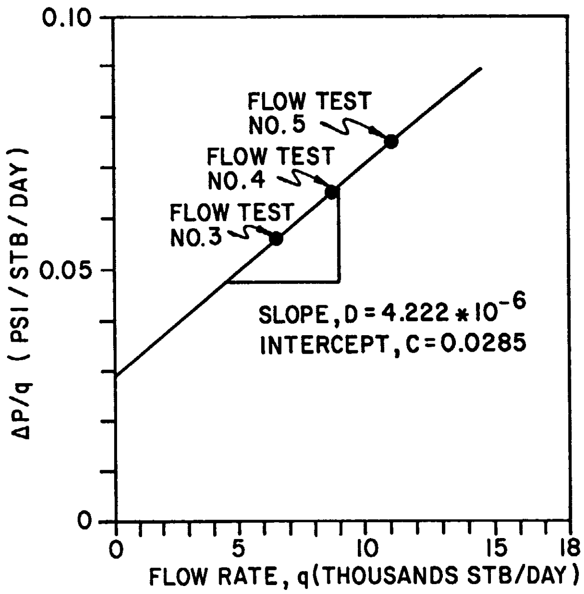

Fig. 1 : Analysis of flow test data for L.R.Sweezy No. 1 well.

In Figure 1, the slope of line, D is 4,222 * 10^{-6}, and the intercept, C is 0.0285. With C and D given, Jones' IPR curve is plotted in Figure 2.

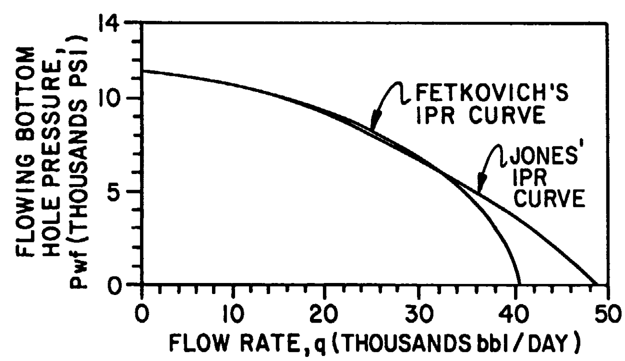

Fig. 2 : Inflow performance curve for L.R.Sweezy No. 1 well.

Method B: Fetkovich's Method

With the same flow test data given in Table 1, Figure 3 shows that log q_o vs. log $(p_r^2-p_{wf}^2)$, plots as a straight line with a slope of 0.66 and a Jo value of 0.178 for an initial reservoir pressure of 11,410 psi.

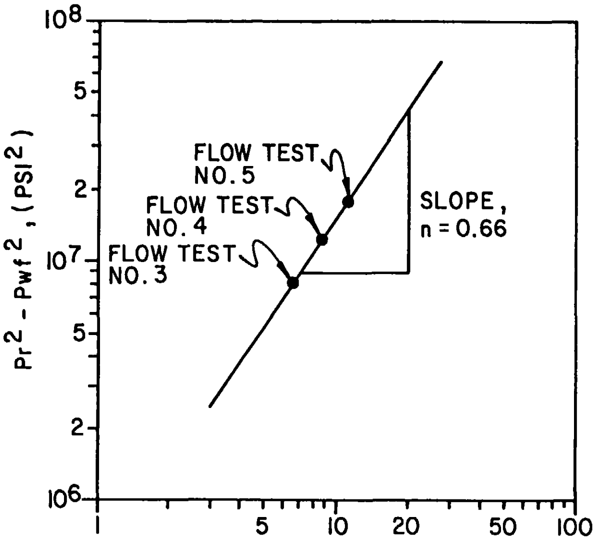

Fig. 3: Flow test performance curve for L.R.Sweezy No. I well.

Using Eq. 3, flow tests for various flowing bottomhole pressures can be calculated. For comparison, Fetkovich's IPR curves is also plotted in Figure 2. The PI values calculated by Jones' and Fetkovich's methods are listed in Table 3.

Eq. 4 was used for future flow rate predictions. Future IPR curves for reservoir pressure of 10,000 psi and 9,000 psi were then plotted in Figure 4. Also, future PI values for a fixed flow rate of 8,000 STB/day are given in Table 4.

TABLE 3.
PI Values Calculated by Jones' & Fetkovich's Methods

Flow Rate (STB/day)	PI value calculated by Jones' method (STB/day/psi)	PI value calculated by Fetkovich's method (STB/day/psi)
4,000	22.0	23.1
8,000	16.1	15.9
12,000	12.6	12.6
16,000	10.4	10.6
20,000	8.9	9.2
24,000	7.7	8.0
28,000	6.8	7.1
32,000	6.1	6.2

TABLE 4: Future PI Values for a Fixed Flow Rate of 8,000 STB/day

Reservoir Pressure (psi)	PI Values (STB/day/psi)
11,410 (current)	15.9
10,000	11.3
9,000	8.5
8,000	6.1
7,000	5.2

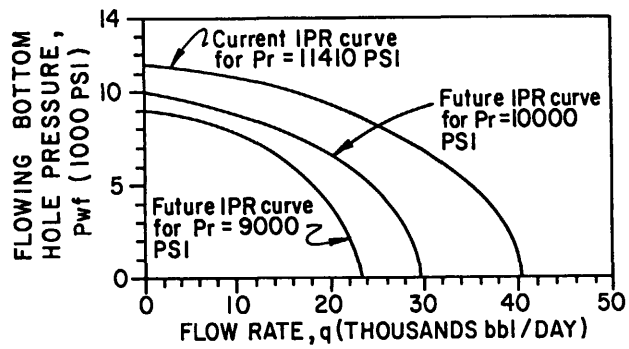

Fig. 4: Current and future IPR curves for L.R.Sweezy No. I well.

DISCUSSION

As shown in Figure 2, Jones' IPR curve is a concave downward curve, which results from high flow rate turbulence effects; the PI decreases as the flow rate increases. For example, at a flow rate of 12,000 STB/day, the PI would be 12.6 STB/day/psi, and the pressure drawdown would be 950 psi. However, if the flow rate increases to 24,000 STB/day, the PI decreases to 7.7 STB/day/psi and the pressure drawdown increases to 3,116 psi.

From Figure 2, it is interesting to note that Fetkovich's and Jones' methods produce very similar IPR curves. The PI value calculated by both methods are quite close to each other, as listed in Table 3. However, the maximum flow rate predicted by Jones' method was larger than that predicted by Fetkovich's method, because, Jones' method is primarily for calculations of one-phase flow, and Fetkovich's method can be used for two-phase flow calculations. Figure 4 shows that the shapes of both current and future IPR curves are similar. Table 4 indicates that the PI value for a fixed flow rate of 8,000 STB/day decreases with decreasing reservoir pressure. However, the nature of the change in the productivity index with reservoir pressure depletion requires further field study.

CONCLUSIONS

The major conclusions reached by this study are:

1. Jones' and Fetkovich's methods each provide more accurate geothermal well performance predictions than does the constant PI method.

2. The productivity index of geothermal wells decreases as flow rate increases. Also, a reduction in reservoir pressure will cause the PI to decrease.

3. Good flow test data are essential for accurate flow rate predictions.

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