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Performance Productivity Curves in Geothermal Systems: A Case of Los Humeros, México

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ABSTRACT

The mechanisms that have a direct influence on geothermal well productivity, are mainly associated with physicochemical characteristics of the reservoir fluids and/or materials. Among these, the chemical composition of the fluids, the physical structures of the formation, such as faults and fractures, the permeability, are some of the parameters that dominate the flow of fluids from the reservoir to the wellbore. The productivity of the wells is a result of the reservoir energy, which in turn is influenced by the characteristics of the media where it is located.

The Los Humeros geothermal field, located in the Mexican Neo-Volcanic belt is a typical example of a reservoir of volcanic origin. In this field it has been identified that the reservoir physical structures have a direct effect on the overall behavior of the wells. More specifically, those wells that are located within the block limited by the same faults, behave in a particular way, and this behavior differs substantially from another wells located in a different block formation that has another faults as boundaries.

It has also been identified that the behavior of the output or IPR curves and their corresponding productivity indices is correlated with among other parameters: The production time, the decline ratio, the formation permeability and corresponding damage, the reservoir thickness and areal extent.

The high drop pressure in relation with the mass production is correlated with some formation damage. So, it affects to decline ratio and productivity indices. The main effect is the flow restriction by obstruction of permeable channels in the rock matrix.

In this work we analyze the productivity of some wells located at the central portion of the Los Humeros, México geothermal field. The behavior of their IPR curves at early production time, lead us to confirm the influence of geological structures over the productivity behavior in the different systems.

1. INTRODUCTION

The well potential is defined as the maximum flow rate that it can contribute under the best set conditions, such as permeability and porosity. These parameters help to the existence so much of hydraulic flow as the presence of recharge characteristics that influence in low drop pressures. For any time, the well productivity can be determined from the fluid properties, depletion reservoir characteristics, thermodynamics conditions, rock physical properties and tubing characteristics (Mach, 1972).

A direct way to determine the well productivity is by the construction of production characteristics curves, also known as output curves. Evinger and Muskat, (1942); Muskat, (1945); Gilbert (1954); Grant et al., (1982) stablished the production curves as a tool to characterize a well and to define operative criteria for the field. Muskat (1945) and Gilbert (1954) were the first authors to use data of well flow rate with the pressure to depth conditions, originating the methodology of IPR curves (Inflow Performance Relationships) also known as inflow curves. A linked parameter with flow-pressure data obtained during delivery tests in wells is the productivity index (J), whose expression is:

$$J = \frac{Q}{\Delta p} \qquad (1)$$

Where Q is the production flow rate at wellhead conditions and Δp is the necessary pressure drop to produce this flow rate. The pressure reference level is taken from stabilized conditions.

The plot of flow rate against well flowing pressure is a right line, when the well flowing pressure is higher than boiling point. But this plot is a curve when there are more than one phase into the reservoir.

Analogously to IPR curves, Geothermal Inflow Performance Relationships (GIPR curves or geothermal inflow type curves) were developed. Such type curves (Moya, 1994; Moya et al., 1995) cover the temperature range from 200 to 350 °C with increments of 25 °C. The methodology proposes the estimation of production characteristic curves of geothermal wells and formation permeabilities from a single measurement of mass flow rate - pressure at wellhead conditions (Moya and Aragón, 1997). Also were considered Corey and linear relative permeabilities. Moya et al. (1995, 1998); Moya and Uribe (2000) showed the application of GIPR curves to determine reservoir characteristics. For wells producing from reservoir at the boiling point, Moya (1994) and Moya et al. (1995) proposed the expression:

$$W^* = 1.0 - 0.256(p^*) - 0.525(p^*)^2 - 0.057(p^*)^3 - 0.162(p^*)^4 \qquad (2)$$

Where W^* and p^* are the dimensionless flow rate and pressure respectively, whose expressions are:

$$W^* = \frac{W}{W_{\max}} \qquad (3)$$

$$p^* = \frac{p}{p_{\max}} \qquad (4)$$

With W as the measured flow rate and W_{max} the maximum flow rate at $p=0$, and p as the measured pressure and p_{max} as the maximum p obtained for $W=0$.

2. STUDY AREA

The analysis area of this work is Los Humeros, México geothermal reservoir, which is located into Mexican neovolcanic belt to more or less 200 km, to east side of México city. The Figure 1 shows the field location, the wells distribution and the geologic structures of the field. From the interpretation of petrologic and petrographics well logs was feasible to know the underground geology (Cedillo, 1997) obtaining the necessary data to identify hidden faults. The correlation of such geologic logs with the sample cuts of drilling helped to classify nine lythologic systems (Viggiano and Robles, 1988a; Cedillo, 1997; Arellano et al., 1998; 2001). The formations found in the production intervals are “Teziutlán” andesites of augite and hornblende andesites.

From a geologic view point it is feasible to observe regional alignments of NW-SE and NE-SW system correlated with Mexican Sierra Madre Oriental. Such structures originated zones of cortical weakness that facilitated the magma grow up. This fact constitutes the heat source of Los Humeros reservoir. So, according with structures alignments and the results of permeability obtained in the exploratory wells located near to faults, it was stablished the depth for each well. The objective was to intersect the structures at a given depth where there was some permeability.

To date 40 wells have been drilled in this field and it has an installed capacity of 35 MWe (Tovar and López, 1998). Also it found that the pressure distribution under initial conditions into the reservoir shows a tendency of a right line (Arellano et al., 2001) whose expression is:

$$p_i = 177.5 - 0.0405(z) \qquad (5)$$

With p_i (the initial reservoir pressure) as a function of z (the depth)

The formation static temperatures calculated with Horner (1951) and sphere (Ascencio et al., 1997) methods, vary into the range from 290 to 350 °C (Arellano et al., 2001). The low temperature values systematically were determined in those wells located at the boundaries of the field.

3. METHODOLOGY

The wells included in this analysis were selected according with their location in the reservoir. In the selection was observed carefully that the production wells were located into the formation bulks resulting of the distribution of faults and fractures along the field. So the wells were grouped by each formation bulk originated by the different structures array (Figure 1). Then the scope of this work was oriented to the reservoir behavior analysis under influence of the geologic faults and fractures.

The average conditions of pressure and temperature for the period time corresponding to measurements of output curves were determined. For this task, we used the logs of pressure and temperature profiles obtained during stabilization stages close in time to the production tests.

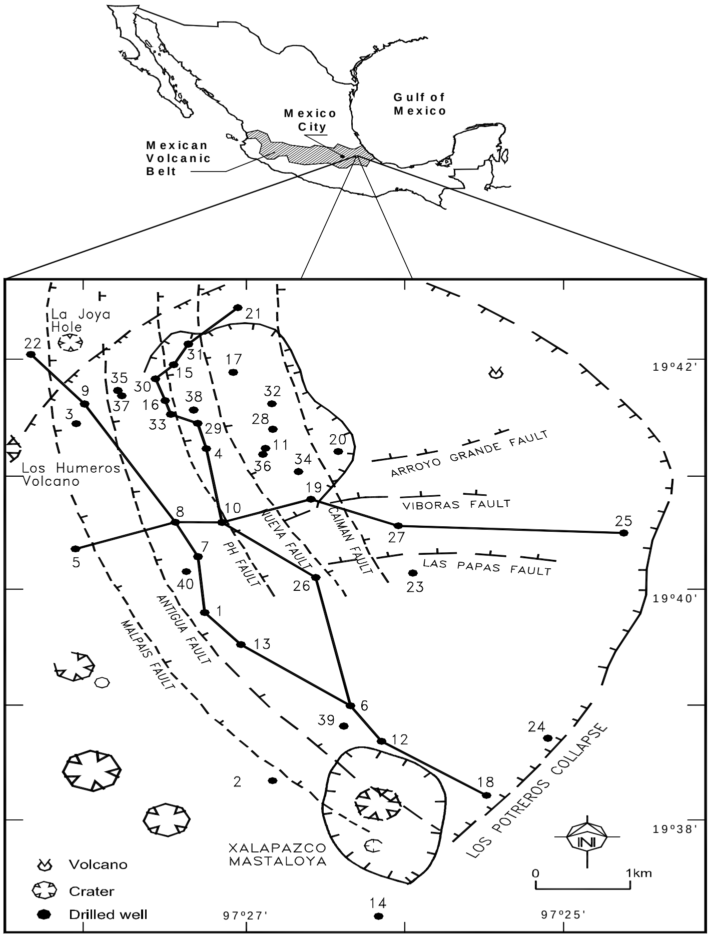

Figure 1: Location of Los Humeros, México geothermal field, (from Arellano et al., 2001) general distribution of wells, structures in the field, and studied wells in this work.

In the analysis we use a pair of values (mass flow rate, wellhead pressure). With the methodology proposed by Moya and Aragón (1997) and the program shown by Moya and Uribe (200) we obtain a complete inflow curve, which is compared with the inflow type curve to obtain the best match. Also it was necessary to select the inflow type curve according with to the pressure and temperature values determined in the well. So, founding the best match with the type curve it is feasible to obtain a permeability diagnosis. In this work we made a sensitivity analysis over the performance of different mass flow rates with the permeability results in the diagnosis. So, we selected value pairs for low, medium and high flow rates.

For each values pair (mass flow rate, wellhead pressure) and using the data of pressure and temperature of each well we taken the corresponding set of inflow type curve in order to start the match. The fine tune of the curve obtained with the measurements and the type curve was allowed by modifying the increment and correction factor values.

The determined values using the permeability diagnosis for the best match with such curves were used in the correlation of the obtained values for the different wells. So, with the values obtained it was feasible to correlate the wells located in the same bulk formation.

4. RESULTS

According with the distribution of geologic structures in Los Humeros, geothermal field we divided the field in three main bulks of formation. The production wells included in this work are grouped into such bulks which are limited by their respective faults. Like can be observed in Figure 1 the bulks with their corresponding wells are the next: (a) Formation bulk limited by the “Caimán” and “Nueva” faults, containing the wells H-11, H-17, H-28, H-32 and H-34; (b) Bulk limited by the “Nueva” and “PH” faults, containing the wells H-15 and H-31; (c) Bulk limited by the “PH” and “Antigua” faults and containing the wells H-16, H-30 and H-35.

We used the parameters shown in the table 1 for to define criteria to select the corresponding set of type curves. The thickness open to formation did not used in this selection, but it is useful in the analysis correlation. It is important to take the pressures and temperatures at stabilized conditions in each well and in period time, close to the delivery test.

The figures 2 and 3 show two of the plots obtained by the match of the production data of the wells H-16 and H-31, using the inflow type curves (Moya, 1994; Moya et al., 1995). These wells are located in different bulks (Figure 1) by this reason were obtained different values in the permeability diagnosis. The well H-16 is in western bulk and the well H-31 is in the central bulk, where the strength of neighboring blocks influence in a better permeability.

Table 1: Thicknesses open to formation, pressures and temperatures of the analyzed wells, in Los Humeros, México geothermal field.

Well	Thickness open to formation (masl)	Static Pressure (bar)	Static Temperature (°C)
H-11	From 1340 to 1660	100$^{(1)}$	293$^{(3)}$, 300$^{(4)}$
H-15	From 1280 to 1640	109$^{(2)}$	250$^{(3)}$, 275$^{(4)}$
H-16	From 1170 to 1330	140$^{(2)}$	284$^{(3)}$, 311$^{(4)}$
H-17	From 1160 to 1540	101$^{(1)}$	250$^{(3)}$, 275$^{(4)}$
H-28	From 1440 to 1550	166$^{(2)}$	360$^{(3),(4)}$
H-30	From 1320 to 1440	114$^{(1)}$	268$^{(3)}$, 300$^{(4)}$
H-31	From 880 to 1200	145$^{(2)}$	315$^{(3)}$, 349$^{(4)}$
H-32	From 1120 to 1420	150$^{(2)}$	333(3), 380$^{(4)}$
H-34	From 1010 to 1560	133$^{(2)}$	234$^{(3)}$, 240$^{(4)}$
H-35	From 1080 to 1510	106$^{(2)}$	293$^{(3)}$, 329$^{(4)}$

The superscripts used in Table 1 mean that:

$^{(1)}$ It refers that the value was obtained by transient pressure tests.

$^{(2)}$ It refers that the value was obtained by well logs.

$^{(3)}$ It refers that the value was calculated using the Horner (1951) method.

$^{(4)}$ It refers that the value was calculated using the sphere method (Ascencio et al., 1997).

The productivity index for each well was calculated using the equation (1) to the production data. The Table 2 shows a summary of the results obtained of permeability and productivity index for each well using the inflow type curves.

Table 2: Permeability results using geothermal inflow type curves (Moya, 1994; Moya et al., 1995) and productivity indices, calculated from delivery tests in wells of Los Humeros, México, geothermal field.

Well	Permeability (*k*) (mD)	Productivity Index (*J*) (ton/hr)/bar
H-11	3.4	0.43
H-15	11.5	0.70
H-16	7.1	0.50
H-17	4.1	0.40
H-28	2	0.30
H-30	4	0.47
H-31	10.5	0.61
H-32	3.4	0.43
H-34	2.5	0.09
H-35	4	0.53

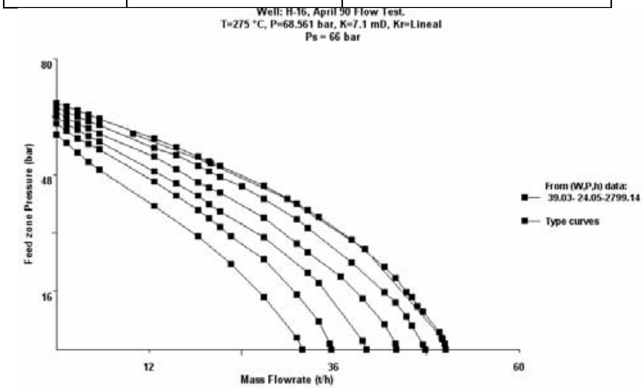

Figure 2: Match using inflow type curve (Moya, 1994; Moya et al., 1995) with data of well H-16 of Los Humeros geothermal field.

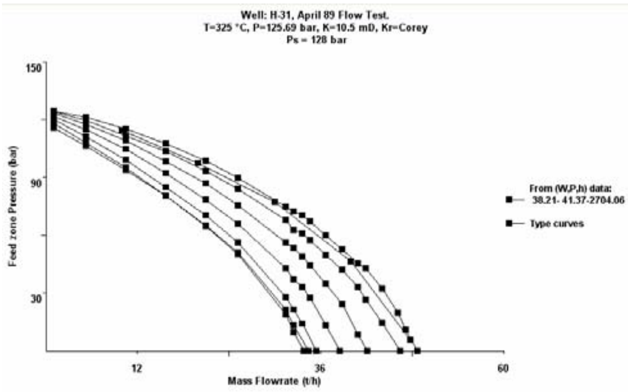

Figure 3: Match using inflow type curve (Moya, 1994; Moya et al., 1995) with data of well H-31 of Los Humeros geothermal field.

5. ANALYSIS AND DISCUSSION

From the analysis results shown in Table 2, it is feasible to define ranges of permeability values and productivity indices for well grouped according with to the structures that limit to the generated formation bulks. So, for the wells located in the bulk limited by the “Caimán” and “Nueva” faults (H-11, H-17, H-28, H-32 and H-34) the permeability values are into the range from 2 to 4.1 mD. And the productivity indices of these same wells are in the range from 0.3 to 0.43 (ton/hr)/bar with exception of well H-34, which is located nearest of outer boundary of production zone. As can be seen in the Table 2 the value of productivity index of this well is 0.09 (ton/hr)/bar, which is smaller to the average for this zone, but its location influences in this value as mentioned above.

For wells H-15 and H-31 which are located in the formation bulk limited by “Nueva” and “PH” faults, were obtained permeability values in the range from 10.5 to 11.5 mD. And the productivity indices determined in these wells vary in the range from 0.61 to 0.70 (ton/hr)/bar.

The wells H-16, H-30 and H-35 are located in the formation bulk limited by the “PH” and “Antigua” faults. So, for theses wells the permeability values were calculated in the range from 4 to 7 mD. And the productivity indices obtained, vary in the range from 0.47 to 0.53 (ton/hr)/bar.

The value ranges of studied parameters in the analyzed wells, show similar characteristics for these wells according with the formation bulk in which they are located. Under this view point the parameter values determined in wells of the central bulk are slightly greater to the parameter values of those wells located in the lateral bulks.

So, even the volcanic formations in Los Humeros geothermal reservoir show characteristics of low permeability, it is feasible to identify values of permeability and productivity indices associated to each formation bulk.

6. CONCLUSIONS

It has been shown the feasibility of using the geothermal inflow type curves for to make permeability diagnosis in wells of Los Humeros, México geothermal field. The permeability results obtained with this methodology are similar to that obtained applying the methods of transient test pressure analysis.

The obtained values from the permeability diagnosis, show that the behavior of wells located in a fractured system, such as where is located Los Humeros, is influenced by the presence of geologic structures.

The best characteristics values of permeability and productivity indices were obtained in those wells located in the central block. It is due to the structures that influence in a higher fracturing of blocks, facilitating by this way, the flow of fluids.

The lowest values ranges of permeability and productivity indices were obtained in the wells located in the eastern formation bulk of the field, where apparently not geologic structures exist (Figure 1).

The results of this work show that the geologic structures of the Los Humeros geothermal field originate bulks of formation. The characteristics of permeability and productivity of each well have single behavior according with each formation bulk.

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