A Review of the Production Parameters for Analysis of the Reservoir Performance

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ABSTRACT

In this paper we used the methodology applied for determining the damage effect from the production measurements. The maximum mass flow rate (W_{max}) and the static pressure (p_e) used in that methodology as variables into de global procedure, are used in this work as technical tool for reservoir characterization. Both parameters are used for calculation of the dimensionless values of W_D and p_D, which are graphed on the type-curve for determining the damage effect in a well. So, by this reason in this work we consider to those as intermediate variables in the application of the methodology above mentioned. In this work, production data of 17 of the wells incorporated to an exploitation continuous system were used. The methodology for determining the damage effect was applied and the results allow us to assume a correlation between production decline of the well and its exploitation time. In a same manner it can be observed that with exploitation time, values of W_{max} and p_e decrease for the same period of time. From the correlative analysis it was found that the methodology applied is useful in the characterization analysis of the interesting zones of the reservoir.

Using the determined values of W_{max} and p_e with data of geographical location of the wells, it was possible to identify the distribution of such parameters along the reservoir area. Besides, using the values at initial conditions, it can get, among others, the distribution of the mass flow rate, static pressure, enthalpy etc., along the reservoir at its initial state. In this work we used, according to the methodology above mentioned, data of production measurements of wells incorporated to continuous exploitation system. The measured data in those wells were at three different discharge orifices. The obtained results allow us, to assume the presence of decline in the system, caused by continuous exploitation. Also were obtained the distribution of the calculated parameters along the reservoir. So, using this methodology it was possible to formulate technical criteria for the exploitation design of the wells.

Introduction

The reservoir characterization involves different technical disciplines and is a useful task for defining their behavior and to establish their future design of operation. According to the study orientation, there are characterizations of the type geological, mineralogical, physical, thermodynamic, petrophysical, etc. In order to obtain a complete knowledge of the reservoir it is necessary to include the major quantity of information from all technical areas. The main objective of a best characterization is to improve the reservoir performance and diminish its decline.

The behavior of wells with limited entry, will be a function of an equivalent spherical permeability that in turn will depend on the reservoir vertical anisotropy (Ahmed, and McKinney, 2005). But in fractured formations, the well´s behavior will depend on variables as fracture length, mobility, capacity, etc. Quantifying the reservoir heterogeneities will be useful to correct the assessment of the long term reservoir potential.

The methodology for reservoir characterization is developed in two stages; the first one is a static characterization and the second is the dynamic characterization. The physical characteristics of the rock volume at static conditions are defined in the first stage, while, in the second stage is described the interaction of the fluids into the rock volume under dynamic conditions (Craft, et al., 1990).

In the first stage, the static model is defined by the reservoir geometry and are described the petrophysical parameters, in order to understand the reservoir system from a physical and geological view point. Information of geologic and geophysical exploration, and chemical analysis of samples from hot spring is used. The data from well logs with their petrophysical and lithologic properties are used.

The dynamic model is the result of the analysis of dynamic interaction between fluid and reservoir rock and the basic objective is the development of methodologies that allow understand the flow of fluid through porous media. This information is useful as input data in numerical reservoir modeling.

The main technical tools used in dynamic characterization are among others: PVT (Pressure, Volume, Temperature) fluid analysis (from the produced fluids); Determination of the relative permeability curves, and capillary pressures (from analysis of core samples); Analysis of the production data; Development and analysis of pressure tests, etc. (Craft et al., 1990).

In this paper we carry out an analysis over dynamic characterization using production data of 17 of the wells, (Goyal et al., 1980; Hiriart and Del Rio, 1995; Quijano and Gutiérrez, 2000) located along the exploitation area of Cerro Prieto Mexican geothermal field. The reservoir characterization from a viewpoint of its production is focused to analysis of its decline behavior, whose diminution of its energy is due to exploitation time. The reservoir decline is manifested by reduction in its productive characteristics (Mass flow rate, pressure, enthalpy, etc.)

The pressure maintenance in the reservoir is due to substitution of the extracted fluids from reservoir rock. The pressure maintenance could be by natural way, through the migration of the fluids from the external border and the displacement of fluids in the reservoir. An artificial way for pressure maintenance is by injection of fluid into the reservoir, taking care in the design of this operation to avoid turbulences of the flow. So a good characterization of the reservoir is useful in the application of any operation in the well.

The variables mainly influencing the production behavior in the reservoir, are pressure, mass flow rate, enthalpy, permeability, porosity etc. In the methodology for determining the damage effect from production measurements (Aragón et al., 2008), maximum mass flow rate (W_{max}) and static pressure (p_e) are variables calculated in intermediate steps. Both variables are used for determining the dimensionless values W_D, p_D, that are graphed into the type-curve affected with damage.

In this work it was found that the damage effect values, calculated in wells analyzed, were increasing as a function of its exploitation time, and inversely the W_{max} and p_e values were decreasing.

Conceptual Frame

The characterization results can be represented in bidimensional and/or tridimensional form. The joint estimations are a recommended technique, which correlates more than two variables for a best determination. The logical process indicates that the first step is the facies modeling and after, the petrophysical properties modeling (such as porosity, permeability, grain density etc.). The interesting petrophysical properties are highly correlated with facies type. So, the knowledge on the facies distribution is a main condition over the porosity and permeability variability, along the reservoir.

The tridimensional characterization uses as input data the wells location and the characterization variable (pressure, mass flow rate, enthalpy, temperature, etc). In this work due that we use production measurements, the reservoir characterization is of dynamic type. According to the availability of the information we selected a section of Cerro Prieto geothermal field of México (Hiriart and Del Rio, 1995; Quijano and Gutiérrez, 2000). Besides, this field is in homogeneous formation and shows minor obstacles than those in volcanic and fractured formations. Therefore, we selected carefully production data of wells, whose measurements were done at uniform periods of exploitation time, in order to fix a same reference level for all analyzed wells.

From the available information, in the analyzed wells, were determined the production parameters at initial conditions in the reservoir. Similar determinations were done at the same wells, after five years of continuous exploitation. Using well flow simulators, were calculated static pressure (p_e), enthalpy (h) and temperature (t) at initial conditions and after five years of continuous exploitation. Similarly through the applying of the methodology for determining the damage effect using production measurements, were calculated the maximum mass flow rate (W_{max}) for initial conditions and after five years of continuous exploitation. Were made data bases containing wells location, their production parameters, measured and calculated, for initial conditions and after five years of continuous exploitation.

Behavior Analysis from Production Data

It was used the methodology for determining the damage effect. As can be seen (Aragón et al., 2008) in this methodology were calculated the reservoir pressures and their corresponding maximum mass flow rate for each period time. As we mentioned before, the determination of these variables is involved in the general process for determining of the damage effect. So in the process, static pressure (p_e) is calculated from the mass flow, pressure, enthalpy (W, p, h) measured at wellhead conditions. For obtaining the parameters at bottomhole conditions were used well flow simulators WELLSIM (Freeston and Hadgu, 1988; Gunn and Freeston, 1991; Hadgu et al., 1995) and VSTEAM (INTERCOMP, 1981). After calculating p_e, the determination of dimensionless pressure (p_D) was done with the expression (Klins and Majcher, 1992; Gallice and Wiggins, 1999):

$$p_D = \frac{p}{p_e} \tag{1}$$

Having calculated p_D, it was determined the dimensionless mass flow rate W_D through the use of inflow performance relationship (Aragón et al., 2008):

$$W_D = 1 - 0.439(p_D) + 1.166(p_D)^2 - 4.307(p_D)^3 + 3.669(p_D)^4 - 1.378(p_D)^5 \tag{2}$$

So, knowing the dimensionless mass flow rate, it can be calculated the value of the maximum mass flow rate, by solving W_{max} in Equation 3.

$$W_D = \frac{W}{W_{max}} \tag{3}$$

The determined values of p_e and W_{max} correspond to the stage of the well´s life in which production measurements were carried out. Due to the exploitation time, ordinarily these values show some decrease, and in this paper are used for determining the behavior of the pressure distribution along the reservoir. Therefore, through the calculated parameters, it can be known the state of the reservoir along the different stages of its operative life.

The decline type in a well is a function of its exploitation rate, of exploitation time and of the reservoir properties. One of the technical tools used in the analysis behavior of reservoir, is the correlation of mass flow rate, static pressure, enthalpy etc. as function time. In this paper is shown the applicability of such correlation using production data of some of the wells of the Cerro Prieto geothermal field.

The evaluation of the different parameters influencing in the behavior of the reservoir productivity are the technical base in the taking decisions for establish the exploitation designs (Grant et al., 1982). Besides, from the knowledge over distribution of these parameters along the reservoir it is feasible to identify the potential zones for new developments.

Analysis of Field Data

It was selected available information for using in the analysis of pressure distribution along the reservoir, for two different periods time (initial conditions and after five years of continuous exploitation). It was used the period time of five years, for all wells, in order to make a fair comparison between them and to identify their decline during this period time.

A special care was taken in the correlation of mechanical completion, and thickness open to formation of all wells. The selected wells of Cerro Prieto geothermal field are located along CPI, CPII and CPIII. Table 1 shows the obtained results, of W_{max} and p_e, by applying the methodology for determining the damage effect (Aragón et al., 2008). Those values were calculated for initial conditions and after five years of continuous exploitation, as intermediate steps of the process.

As can be seen in Table 1, the majority of the wells are completed at mean depths less than 2000 m with exception of five of these wells whose depths are greater than 2500 m. The thickness of the wells are in the mean range of 360 m, with exception of wells 6, 10, 15 and 23, whose thickness values are of 745, 706, 544 and 591 m respectively.

The average mass flow rate of the group of analyzed wells at initial conditions, is estimated in about 315 t/h, excluding three of the wells with productions upper and minor, of the ordinary rank. The wells 1, 7 and 9 resulted with production of mass flow of 102, 588 and 581 t/h respectively. After five years of continuous exploitation, the estimated mean of mass flow was about 120 t/h.

The mean static pressure at initial conditions shown less variation respect to the mass flow rate and was estimated in 177 bar, and after five years of continuous exploitation, the mean static pressure was estimated in 120 bar.

Using the data of wells location and the calculated static pressure (p_e), as characterization parameter, were constructed maps of isobars and tridimensional representations of pressure distribution along the field. As mentioned before the analysis of the pressure distribution was carried out, for initial conditions (Figure 1) and after five years of continuous exploitation (Figure 2).

Table 1. Analysis of the behavior mass flow rate and pressures in 17 of the wells of Cerro Prieto Mexican Geothermal field.

Well No.	W_{max} (t/h)		p_{est} (bar)		Depth	Thick-ness
Well No.	At initial conditions	After 5 years of continuous exploitation	At initial conditions	After 5 years of continuous exploitation	(m)	(m)
1	102.6	77.1	140.0	110	1,996.45	478.50
2	468.8	101.8	185.0	97	1,950.00	513.00
3	341.3	73.2	100.0	75	1,814.60	468.60
4	461.5	117.1	150.0	120	1,910.50	407.50
5	455.3	193.7	250.0	200	1,965.54	122.50
6	241.6	157.3	200.0	140	3,098.52	745.60
7	587.8	138.6	220.0	135	2,122.53	505.50
8	288.8	77.1	110.0	80	1,795.90	400.90
9	581.1	172.5	250.0	170	1,793.50	383.50
10	364.3	192.1	300.0	200	1,966.50	706.50
11	283.6	47.6	85.0	40	1,780.20	404.20
14	248.4	172.5	250.0	170	1,798.02	313.00
15	251.5	105.2	150.0	110	2,068.50	544.50
18	262.2	84.5	130.0	80	2,565.50	419.50
20	274.2	131.1	190.0	140	2,545.10	331.10
23	480.2	113.9	150.0	110	2,997.50	591.50
26	473.6	96.2	150.0	90	2,480.17	377.20

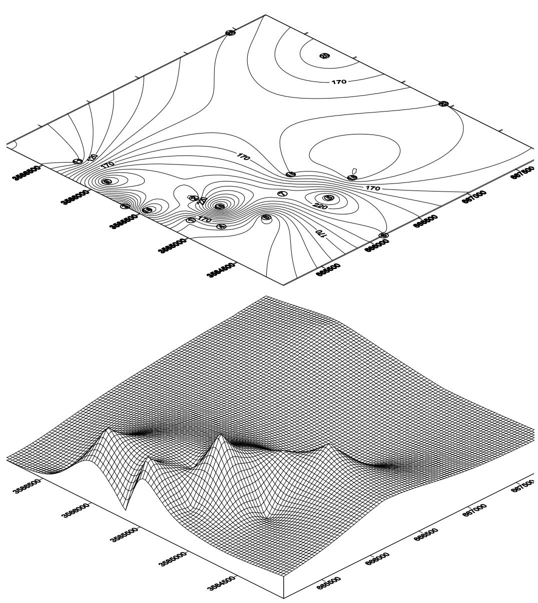

Figure 1. Distribution of static pressure (p_e) along the CPI, CPII and CPIII areas of Cerro Prieto reservoir at the initial conditions.

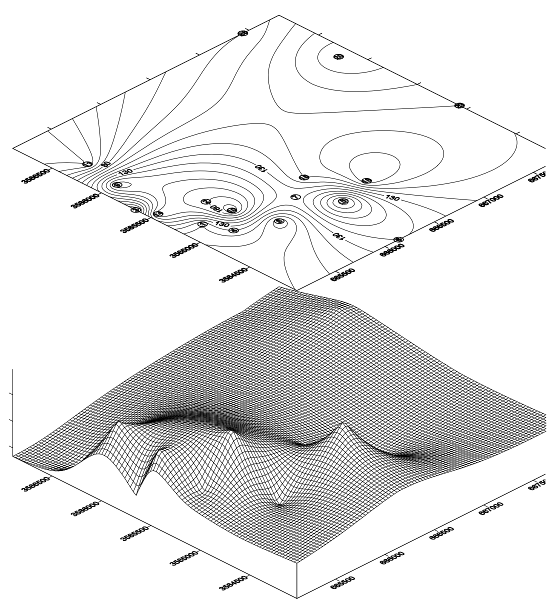

Figure 2. Static pressure (p_e) distribution along the CPI, CPII and CPIII areas of Cerro Prieto reservoir after five years of continuous exploitation.

Discussion Results

From the obtained results of W_{max} and p_e at initial conditions and after five years of continuous exploitation, were calculated the percent decreases per year of both parameters. Table 2 shows the values of the mass flow rate and static pressure at initial conditions with theirs respective percent decreases per year.

As can be seen in Table 2 the values of mass flow rate are two times higher than the static pressure and in the same rank are the differences in percent decrease. The mass flow rate variation decreases in mean percent value of 13.2 %, while the mean percent decrease of static pressure was calculated in 6.3 %.

Table 2. Values of mass flow rate and static pressures at initial conditions and the corresponding percent decrease per year in the analyzed wells.

Well No.	$(W_{max})_i$ (t/h)	Δ% W	$(P_e)_i$ (bar)	Δ% p_e
1	102.6	4.9	140.00	4.3
2	468.78	15.6	185.00	9.5
3	341.33	15.7	100.00	5.1
4	461.52	14.9	150.00	3.9
5	455.34	11.5	250.00	4.1
6	241.6	6.9	200.00	5.9
7	587.87	15.3	220.00	7.7
8	288.83	14.7	110.00	5.4
9	581	14.1	250.00	6.4
10	364.34	9.4	300.00	6.6
11	283.58	16.6	85.00	10.6
14	248.44	6.1	250.00	6.4
15	251.53	11.7	150.00	5.3
18	262.25	13.6	130.00	7.7
20	274.17	10.4	190.00	5.3
23	480.18	15.3	150.00	5.3
26	473.6	15.9	150.00	7.9

where subindex (i) denotes initial condition.

Conclusions

Applying the methodology for determining damage effect from production measurements, mean values of maximum mass flow rate (W_{max}) and static pressure (p_e) of 17 analyzed wells were determined, at their initial conditions and after five years of continuous exploitation.

With the study carried out, was demonstrated that the methodology above mentioned, also is useful for determining parameters used in the reservoir characterization.

From the correlation between analyzed wells using the obtained results, were constructed maps of static pressure distribution (p_e), at initial conditions and after five years of continuous exploitation.

Through the knowledge of behavior of the parameters and their distribution along the reservoir is feasible to establish or modify the exploitation design of the field, and/or the development of the new exploration areas.

From the percent decrease of mass flow rate and static pressure along the analyzed period time it is inferred the presence of decline in the studied section of the reservoir.

The characterization developed using the behavior of the static pressure along the CPI, CPII and CPIII areas of Cerro Prieto, allows identify the zones in the reservoir with major decreases, in order to introduce changes in the exploitation management to improve the field productivity.

By comparison of distribution maps using several parameters it can be possible to define with reasonable certainty the global behavior of the reservoir, which is useful in the establishment criteria about the best management of the field.

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References

Ahmed, T., McKinney, P.D., 2005. "Advanced reservoir engineering". Gulf Professional Publishing, Elsevier, Burlington, MA, USA, 421 pp.

Aragón, A., Moya, A. S., García-Gutiérrez, A., 2008. "Inflow performance relationships in geothermal and petroleum reservoir engineering: A review of the state of the art", Geothermics, 37, pp. 635-650.

Craft, B., Hawkins, M., Terry, R., 1990. "Applied petroleum reservoir engineering", 2nd Ed. Prentice Hall, New Jersey, U.S.A., 647 p.

Freeston, D.H., Hadgu, T., 1988. "Comparison of results from some wellbore simulators using a data bank". In: Proceedings of the 10th New Zealand Geothermal Workshop, University of Auckland, Auckland, New Zealand, pp. 408–414.

Gallice, F., Wiggins, M., 1999. "A comparison of two-phase inflow performance relationships". In: Proceedings of the SPE Mid-Continent Operations Symposium, Oklahoma City, OK, USA, pp. 235-241.

Goyal, K.P., Miller, C.W., Lippmann, M.J., 1980. "Effect of measured wellhead parameters and well scaling on the computed downhole conditions in Cerro Prieto Wells". In: Proceedings of the 6th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, USA, pp. 130-138.

Grant, M.A., Donaldson, I.G., Bixley, P.F., 1982. "Geothermal reservoir engineering". Academic Press, New York, NY, USA, 369 p.

Gunn, C., Freeston, D., 1991. "Applicability of geothermal inflow performance and quadratic drawdown relationships to wellbore output curve prediction". Geothermal Resources Council Transactions 15, pp. 471–475.

Hadgu, T., Zimmerman, R.W., Bodvarsson, G.S., 1995. "Coupled reservoir-wellbore simulation of geothermal reservoir behavior". Geothermics 24, pp. 145–166.

Hiriart, G., Del Rio, L., 1995. "Mexican experience in geothermal power generation". In: Proceedings of the 1995 World Geothermal Congress, Florence, Italy, pp. 2025-2030.

INTERCOMP, 1981. "Vertical steam-water flow in wells with heat transfer – VSTEAM, user´s manual". INTERCOMP Resource Development and Engineering, Inc. Houston texas, U.S.A., 45 p.

Klins, M.A., Majcher, M.W., 1992. "Inflow performance relationships for damaged or improved wells producing under solution-gas drive". Journal Pet. Tech. 44, pp. 1357–1363

Quijano, L.J., Gutiérrez, N.L., 2000. "Geothermal production and development plans in México". In: Proceedings of the 2000 World Geothermal Congress, Kyushu–Tohoku, Japan, pp. 355–361.