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THE USE OF INFLOW PERFORMANCE RELATIONSHIPS TO IDENTIFY RESERVOIR RESPONSE DURING PRODUCTION TESTS IN A GEOTHERMAL WELL

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ABSTRACT

The behavior of four inflow performance relationships are analyzed and discussed. Two of them are developed for petroleum systems and two others are developed for geothermal fluid containing high and low salinity respectively. A methodology to determine the maximum flow rate (W_{max}) that a well can produce for a specific stage of its productive life, using these inflow relationships is presented. Also it is showed the way to identify the intervals of the dimensionless pressure values (p_D), for which the maximum flow rate can be considered as stable and as a reservoir response according to its bottom flowing pressure (p_{wf}). Application of this methodology to four cases of production test in wells was carried out, founding that the intervals of p_D values where the stabilized flow is identified is a function of the magnitude of the well flow capacity.

INTRODUCTION

Reservoir engineering for well characterization uses among other tools, the inflow curves also known as IPR curves (Inflow Performance Relationships). The inflow curve of a well is equivalent to the output curve but it is measured at bottom hole conditions. Both curves are individuals for each well and vary with the productive life of the well. The output curves are obtained from the measurements at surface conditions of the flow and pressure.

The original application of inflow curves was done in the petroleum industry (Muskat, 1937; Evinger and Muskat, 1937; Horner, 1951; Gilbert, 1954; Weller, 1966; Vogel, 1968; Wiggins, 1994). Also several authors (Grant et al., 1982; Kjaran and Elliasson, 1982; Garg and Riney, 1984; Chu, 1988; James, 1989; Gunn and Freeston, 1991a) began to utilize the technique of output curves in geothermal reservoirs. Also different geothermal inflow performance relationships were developed assuming the fluid as: a) pure water (Iglesias and Moya, 1990), b) a mixture H_2O-CO_2 (Moya, 1994; Moya et al., 1998), c) a ternary mixture H_2O-CO_2-$NaCl$ with low salinity (Montoya, 2003), and d) a ternary mixture H_2O-CO_2-$NaCl$ with high salinity (Meza, 2005).

INFLOW RELATIONSHIPS

There are many applications of inflow relationships and one of them is the determination of the maximum flow (W_{max}) that a well can produce. The value of the maximum flow is useful in the design of exploitation, and to fix the reference value from which it can identify the decline in the well production. The inflow curves are related by their respective dimensionless relations, which utilize the variables of flow and pressure obtained in a well test production. The dimensionless expressions of these variables are:

$$p_D = \frac{p_{wf}}{p_e} \qquad (1)$$

$$W_D = \frac{W}{W_{\max}} \qquad (2)$$

Where p_{wf} is the bottom flowing pressure, p_e is the static pressure of formation, W is the flow and W_{max} is the maximum flow that the well can produce.

The inflow performance relationships use the variables of flow and pressure, which are measured in a production test of the well. Making these variables in their dimensionless form, we can determine the characteristic value (static pressure or maximum flow that the well can produce).

Among the diverse existing inflow relationships in the petroleum technology, four were selected to use in this work. Two of them are from petroleum engineering (Vogel, 1968; and Wiggins, 1994), whose respective expressions are:

$$\frac{Q_o}{(Q_o)_{\max}} = 1.0 - 0.2\left(\frac{p_{wf}}{p_e}\right) - 0.8\left(\frac{p_{wf}}{p_e}\right)^2 \tag{3}$$

$$\frac{Q_w}{(Q_w)_{\max}} = \left[1 - 0.72\left(\frac{p_{wf}}{p_e}\right) - 0.28\left(\frac{p_{wf}}{p_e}\right)^2\right] \tag{4}$$

Where Q_o is the oil flow rate and $(Q_o)_{max}$ is the maximum oil flow rate, and Q_w is the water flow rate and $(Q_w)_{max}$ is the maximum water flow rate

From the different inflow relationships developed for geothermal reservoirs, in this work we use two of them. One expression (Eq. 5) assumes the fluid is a ternary mixture (H_2O-CO_2-$NaCl$) with low salinity (less than 5 % of mass fraction in liquid phase) (Montoya, 2003); Second expression (Eq. 6) is developed assuming the same ternary mixture but for high salt content (30% of mass fraction in the liquid phase) including precipitation conditions (Meza, 2005). Such respective expressions are:

For low salinity

$$\frac{W}{W_{\max}} = 0.999 - 0.436\left(\frac{p_{wf}}{p_e}\right) - 0.537\left(\frac{p_{wf}}{p_e}\right)^2 + 0.694\left(\frac{p_{wf}}{p_e}\right)^3 - 0.715\left(\frac{p_{wf}}{p_e}\right)^4 \tag{5}$$

For high salinity

$$\frac{W}{W_{\max}} = 1.0 - 0.4399\left(\frac{p_{wf}}{p_e}\right) + 1.1658\left(\frac{p_{wf}}{p_e}\right)^2 + - 4.0372\left(\frac{p_{wf}}{p_e}\right)^3 + 3.6697\left(\frac{p_{wf}}{p_e}\right)^4 + - 1.3782\left(\frac{p_{wf}}{p_e}\right)^5 \tag{6}$$

Figure 1 shows a comparison of the four inflow relationships analyzed in this work (Vogel, 1968; Wiggins, 1994; Montoya, 2003; Meza, 2005). Three of them have similar behavior; only one, which is the proposed by Wiggins (1994), deviates from three others. The maximum percentage deviations of these three relations vary from 7.1 to 9.2 %, and these occur for values of p_D from 0.4 to 0.6. Table 1 shows the results of W_D obtained using the three relations and the percentage differences among these.

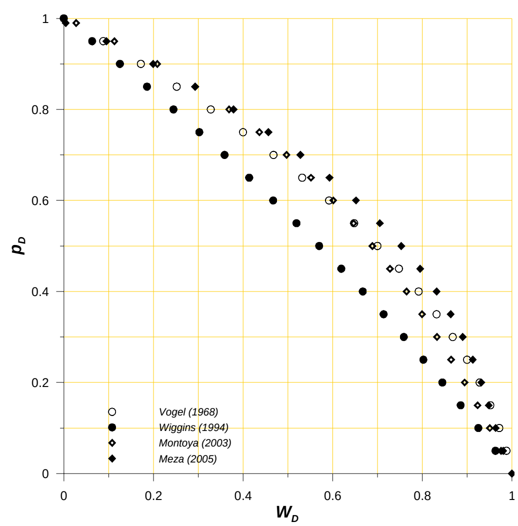

Figure 1. Comparison of the behavior of inflow relationships used in this work.

p_D	W_D			Differences %
	Vogel (1968)	Montoya (2003)	Meza (2005)	
0.40	0.79	0.76	0.83	8.4
0.45	0.75	0.72	0.79	8.8
0.50	0.70	0.69	0.75	8.0
0.55	0.65	0.65	0.71	7.1
0.60	0.59	0.60	0.65	9.2

Table 1. Maximum percentage differences determining WD with three inflow relationships.

Ordinarily the production tests of wells incorporated to continuous exploitation are carried out with only three or four measurements. The required time to obtain conditions of the stabilization in such measurements is a reason for which few data are obtained. Therefore it turns out appropriate, to identify the answer of the reservoir to changes in the production outputs.

It is feasible to utilize the inflow relationships and the linking among the pressure dimensionless (p_D) and the maximum flow (W_{max}) that is obtained from its application in field cases. The objective is to identify the W_{max} average stabilized that is reached with the different openings (or discharge diameters), for which the corresponding value of p_D is obtained. This value is related to the bottom hole pressure and to the discharge diameters.

METHODOLOGY

The set of values that are required for the application of the inflow relationships are the flow and the bottom hole pressure (p_{wf}) of the well during a production test. Nevertheless, due to the mass that the well discharges, it is a complicated task to measure its bottom conditions during a production test. Ordinarily flow simulators in wells are used to determine bottom conditions from their corresponding surface measurements. It is recommended to have a flow simulator applicable to the characteristics of the field in order to obtain results with confidence.

The routine application of the inflow relationships assumes knowledge of the static pressure of the formation before the production test. Subsequently the value of the bottom pressure (p_{wf}) is used for a measured flow and both values in the corresponding expression (Eqs. (3), (4), (5) or (6)) are incorporated. The result is the dimensionless flow (W_D). Subsequently, applying Eq. (2), the maximum flow (W_{max}) that the well can produce, can be determined

A graph of p_D against W_{max} is built and the stabilized value of the maximum flow is identified. From the same plot, the rank of values of p_D for the stabilized flow can be determined.

APPLICATIONS

The methodology described above, was applied to data of production tests of the Carry City well (Gallice and Wiggins, 1999), and of the Cerro Prieto wells, M-110 and M-200 (Ribó, 1989). The pressure values reported by Gallice and Wiggins (1999) correspond to the bottom conditions of the Carry City well, and in the Fig. 2 its inflow curve is shown. The reported data (Ribo, 1989) for the two production tests of well M-110 (in 1979 and 1987) and one production test of well M-200, are at wellhead conditions. Their corresponding output curves are shown in Figs. 3 and 4. Using well flow simulators (Goyal et al., 1980; Gunn and Freeston, 1991b; Moya et al., 2003) the respective bottom hole conditions were determined, resulting in their inflow curves which are shown in Figs. 5 and 6.

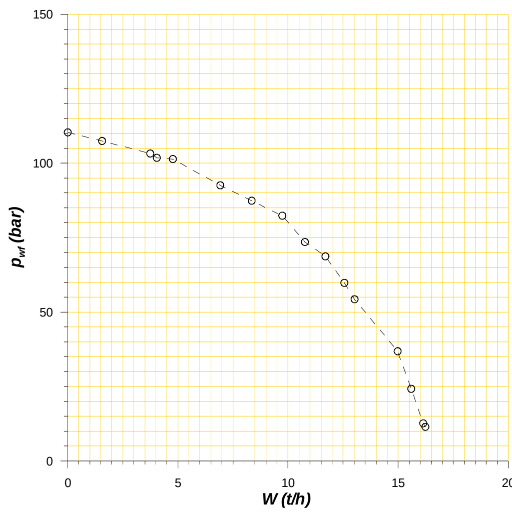

Figure 2. Inflow curve of well Carry City (Gallice and Wiggins, 1999).

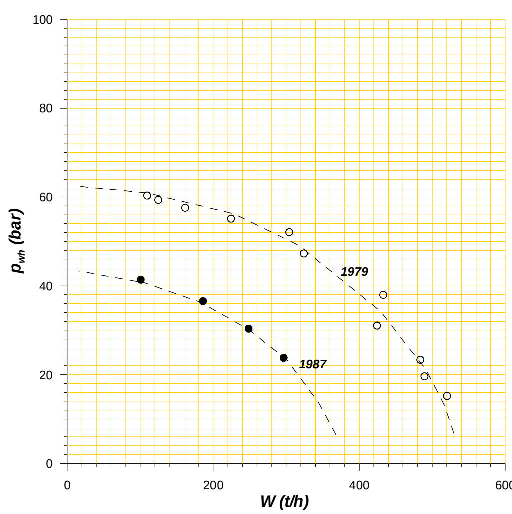

Figure 3. Production output curves of well M-110, from production test conducted in 1979 and 1987 (Ribó, 1989).

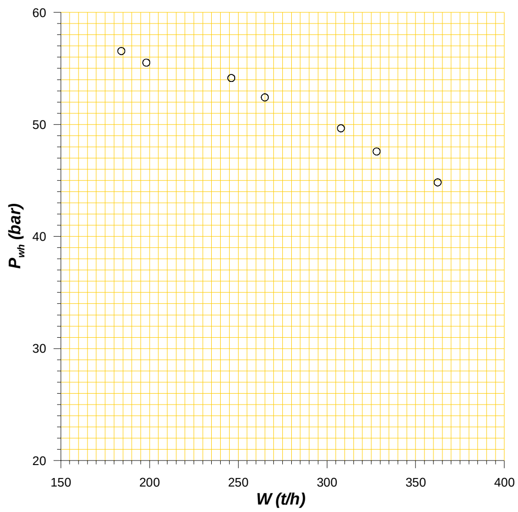

Figure 4. Output curve of well M-200 (Ribó, 1989).

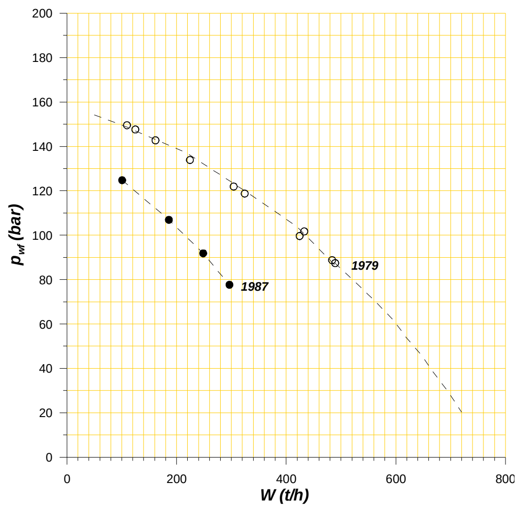

Figure 5. Inflow curves of well M-110, determined from production test data of 1979 and 1987.

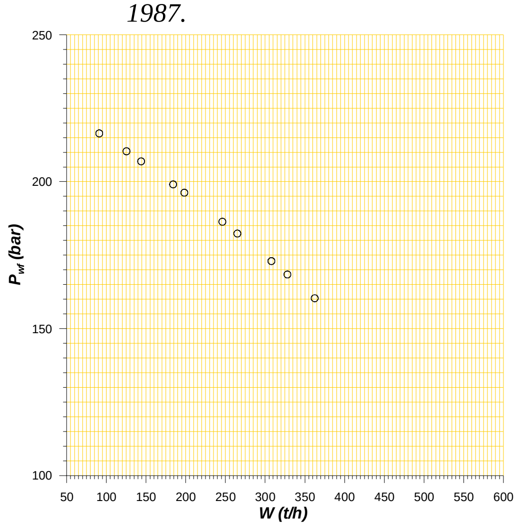

Figure 6. Inflow curve of well M-200, determined from production test data of 1985.

Using the inflow data of each production test in the four inflow relationships analyzed in this work (Eqs. 3, 4, 5 and 6), their respective values of maximum flow rate (W_{max}) were determined. Graphs of W_{max} against their corresponding values of dimensionless pressure (p_D) were built. The W_{max} determined as a response of the reservoir results from the average value of calculated W_{max} in its stabilization interval (Figs. 7, 8, 9 and 10 for each production test).

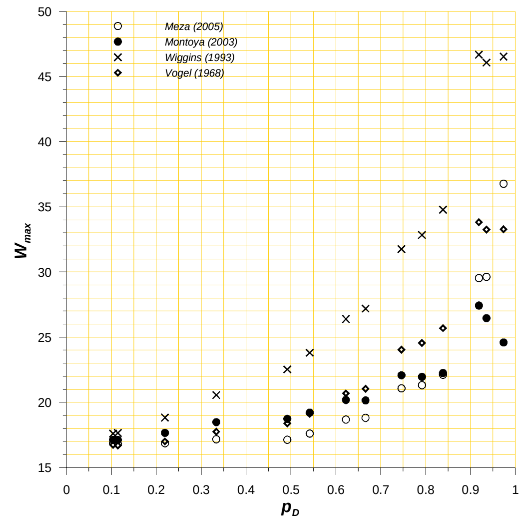

Figure 7. Behavior of p_D against W_{max} using the four inflow relationships with Carry City well data.

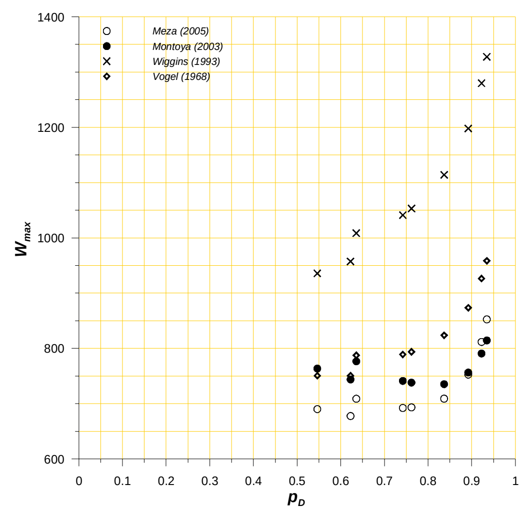

Figure 8. Behavior of p_D against W_{max} using the four inflow relationships with production test data of 1979 from well M-110.

In the Table 2 the average values of W_{max} are shown in the interval in which they remain stable. In the same table, the percentage differences in the calculation of this value are included for the four relations and eliminating the relation with which greater deviations are obtained, that is that of Wiggins (1994).

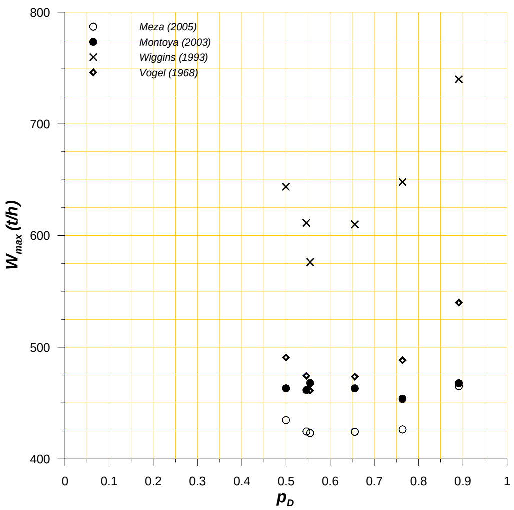

Figure 9. Behavior of p_D against W_{max} using the four inflow relationships with production test data of 1987 from well M-110.

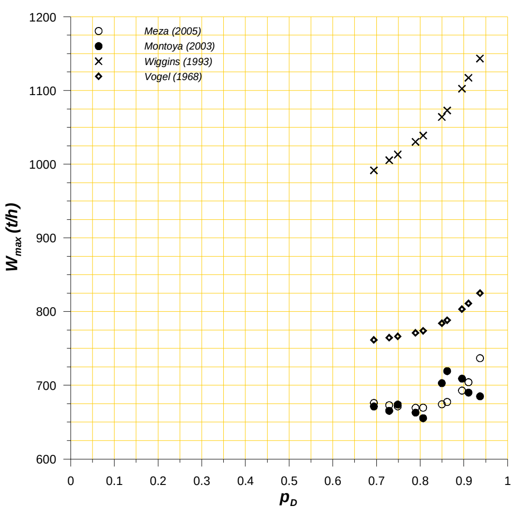

Figure 10. Behavior of p_D against W_{max} using the four inflow relationships with production test data of 1985 from well M-200.

Well	W_{max} (t/h)				Difference (%)	
	Vogel (1968)	Wiggins (1994)	Montoya (2003)	Meza (2005)	Not including Wiggins	Including Wiggins
Carry City	17.6	20.2	18.1	17.1	5.5	15.3
M-110 (1979)	782	1018	749	695	11.1	31.7
M-110 (1987)	474	611	461	424	10.5	30.6
M-200	767	1024	662	671	13.7	35.4

Table 2. Average values of W_{max} and percentage differences in the interval of stability, determined with the four inflow relationships used in this work.

RESULTS AND DISCUSSION

The determined value of W_{max} (Table 2) corresponds to the maximum flow that the well can produce for the conditions in which the test is performed and is the one that is utilized for the design of field exploitation.

From the four inflow relationships used in this work, it is found that the proposed relation by Wiggins (1994) is the one that shows greater deviation for the calculation of W_D and by consequence in the calculation of W_{max} (Table 2).

The obtained deviation in the results with the relation proposed by Wiggins (1994) is related mainly with the supposition of the type of fluid with respect to the type of fluid considered in the other three relations. The supposition of Wiggins relation does not consider presence of gas in the flow.

The percentage deviation in calculation of W_{max} (Table 2) is a function of the magnitude of the flow value.

From Eq. 2 it can be seen in Table 2 that p_D is related to p_{wf}, and it is function of the discharge diameter. By identifying the intervals in which the stability of W_{max} with respect to p_D is reached, it is feasible to identify the appropriate conditions that the discharge through a specific opening corresponds to optimal reservoir production.

CONCLUSIONS

A revision of four inflow relationships was conducted, two originally developed for petroleum systems and two considering the geothermal fluid as a ternary mixture (H_2O-CO_2-$NaCl$) with high and low salinity, respectively.

A methodology to determine W_{max} from the inflow relationships and its corresponding value of p_D is presented.

From the obtained results it is possible to identify the ranks of p_D values for which W_{max} values are stabilized.

The intervals of p_D values for which W_{max} values are stabilized, is a function of the magnitude of well flow capacity.

From the four inflow relationships utilized in this work, maximum flows calculated with the four equations are related to corresponding diameters of opening through the dimensionless pressure (p_D).

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