The Damage Effect Determined From Inflow Type-Curves, and its Relation with Production Decline

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ABSTRACT

A review is made of the parameters that play a role in the well productivity. Also the characteristic production curves and inflow curves are mentioned as a useful tool, to analyze the well behavior. The theoretical development of the inflow curves, applied to petroleum and geothermal reservoirs is described. The equations to determine the damage effect are shown and the type-curve to be applied to calculate the damage effect from production measurements, is presented. Also in this work it is mentioned that the well production decline is a correlated effect with its exploitation. The analysis of the behavior of the inflow curves of wells located in mexican geothermal fields, is described. The analyzed inflow curves were obtained from production tests carried out in different stages of exploitation. With the overlaying of the data of the dimensionless curves on the graph of the type-curve, the damage values were determined, for each stage in which the production tests were carried out. The obtained results emphasized that the damage value increases with the decline productivity of the wells, which is linked to exploitation time.

Introduction

The productivity in a well is a dependent variable of parameters such as the pressure, the temperature, the enthalpy, and the petrophysical characteristics as the porosity, permeability, thickness etc. An influence factor determining the productivity in a well is the damage effect and it has been found that the decline productivity is related with it (Hurst, 1953; Chen and Chang, 2003).

In analyzing the behavior of the parameters that influence well productivity, it is feasible to identify that the petrophysical properties (ϕ, k, h) remain constant. However the reservoir conditions (pressure, temperature, enthalpy) show changes with exploitation time. These changes, ordinarily are in decreasing sense but the damage effect increases.

The equation of Darcy in the form as proposed by Muskat and Evinger (1942) uses the variables that control the flow of fluid in the reservoir, and its expression is:

$$Q = \frac{0.00708kh}{\left[\ln\frac{r_e}{r_w} - 0.75 + s\right]} \int_{p_{wf}}^{p_r} f(p)dp \tag{1}$$

where Q represents the volumetric flow rate, k the permeability, h the thickness formation, r_e the drainage radius, r_w the well radius, s the damage effect and p the pressure. The pressure function varies between the value of bottom-hole flowing pressure (p_{wf}) and the reservoir pressure (p_r).

The value of the damage effect normally is obtained from the transient pressure tests. However the long periods that are needed to overcome the transient effects make it difficult to dispose of wells integrated into the operating systems. By this reason, during the exploitation stage of the wells, the transient pressure tests are carried out in those that present problems, such as big drawdowns of the pressure or severe decreases in the productivity. The Horner´s (1951) method, for the analysis of transient pressure tests, establishes the equations for the determination of the values of permeability, porosity and damage in a well. The expression for determining the damage (s) is:

$$s = 1.151\left[\frac{\Delta p}{m} - \log t - \log\frac{k}{\phi\mu C_t r_w^2} + 3.23\right] \tag{2}$$

where Δp is the differential pressure, m is the slope of the segment of the line in the graph of log (t) versus Δp, t is the time, ϕ is the porosity formation, μ is the fluid viscosity, C_t is the compressibility of the system.

The transient pressure tests are a useful tool to characterize the well and often are used during the well completion and in the previous stages to the continuous exploitation. However during the exploitation stage is a common practice to carry out production tests in the wells, in order to determine parameters to construct their characteristic curves. The characteristic curves (of production) relate the flow rate with the wellhead pressure and are used to establish criteria for designs of exploitation (James, 1989). From the behavior of the characteristics curves measured at different stages of exploitation is feasible to identify the well decline. The well decline, as can be seen in Equation (1), is related with the decreases of the pressure and the damage effect.

Inflow Relationships

Different authors (Gilbert, 1954; Weller, 1966; Vogel, 1968; Grant et al., 1982; Klins and Majcher 1992; Wiggins, 1994; Iglesias and Moya, 1998; among others) used the inflow relationships for characterize the behavior of wells productivity.

The classical inflow performance relationship applied to petroleum reservoirs was proposed by Vogel (1968), whose expression is:

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

Authors as Standing (1970), Fetkovich (1973), Klins and Majcher (1992) among others, also proposed their own inflow relationships for petroleum reservoirs. However the innovation of major impact, was the incorporation of the damage effect, done by Klins and Majcher (1992). The expression is:

$$\frac{Q_o}{(Q_o)_{\max}} = M\left[1.0 - 0.295\left(\frac{p_{wf}}{p_r}\right) - 0.705\left(\frac{p_{wf}}{p_r}\right)^n\right] \tag{4}$$

where

$$M = \left[\frac{\ln\frac{r_e}{r_w} - 0.467}{\ln\frac{r_e}{r_w} - 0.467 + s}\right] \tag{5}$$

$$n = \left[0.28 + 0.72\left(\frac{p_e}{p_b}\right)\right]\left(1.24 + 0.001 p_b\right) \tag{6}$$

where p_b is the pressure at the boiling point.

For geothermal reservoirs, different authors developed the inflow performance relationships assuming different considerations of the fluid. Iglesias and Moya (1990) considered the fluid as a pure water. Moya (1994) assumed the fluid composed as a mixture of H_2O-CO_2. Moya et al., (1998) considered the fluid as a ternary mixture of H_2O-CO_2-$NaCl$. Montoya (2003) and Meza (2005) assumed the fluid with the same ternary composition and they proposed the inflow relationships for fluid salinity, less than 5% and greater than 5% respectively, of mass fraction in the liquid phase. Aragón et al., (2007) incorporated the damage effect, according to geothermal conditions, in the inflow relationships and they obtained the type-curves with damage effect in order to be applied to geothermal reservoirs. The expression with damage effect for the inflow relationship with fluid salinity greater than 5% of mass fraction in the liquid phase is:

$$\frac{W}{W_{\max}} = M\left[\begin{array}{l} 1.0 - 0.4399\left(\frac{p_{wf}}{p_r}\right) + \\ 1.1658\left(\frac{p_{wf}}{p_r}\right)^2 - 4.0372\left(\frac{p_{wf}}{p_r}\right)^3 + \\ 3.6697\left(\frac{p_{wf}}{p_r}\right)^4 - 1.3782\left(\frac{p_{wf}}{p_r}\right)^5 \end{array}\right] \tag{7}$$

where W is the mass flow rate, W_{max} is the maximum mass flow rate and M is obtained from the expression:

$$M = \frac{\ln\frac{r_e}{r_w} - 0.6603}{\ln\frac{r_e}{r_w} - 0.6603 + s} \tag{8}$$

Figure 1 shows the type-curve of the inflow relationship of the Equation (7), for different damage values.

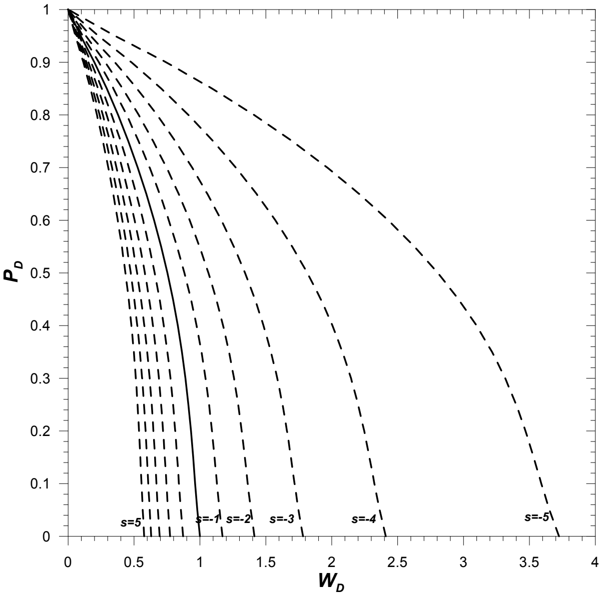

Figure 1. Inflow type-curve with different damage values, obtained for a fluid composed by H_2O-CO_2-$NaCl$ with salt content greater than 5 % of mass fraction in the liquid phase.

The use of the type-curve of Figure 1 for determining the damage value, requires overlaying the dimensionless values (W_D, p_D) of the inflow curve on the graph (Aragón et al., 2009). The dimensionless values for each point of the inflow curve are determined from the next equations:

$$W_D = \frac{W}{W_{\max}} \tag{9}$$

$$p_D = \frac{p_{wf}}{p_r} \tag{10}$$

W_D and p_D are the dimensionless values of the mass flow rate and the pressure.

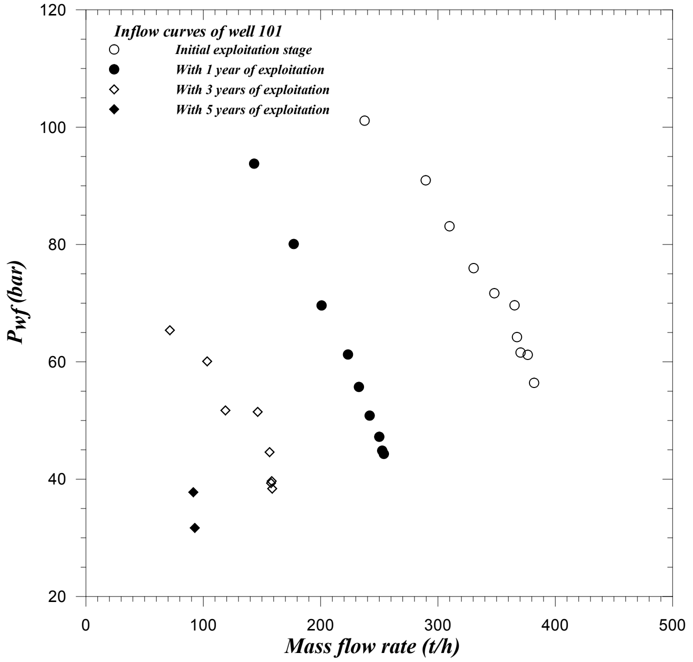

Figure 2. Inflow curves determined at different stages of exploitation of the well 101, of the Cerro Prieto B. C. México, geothermal field.

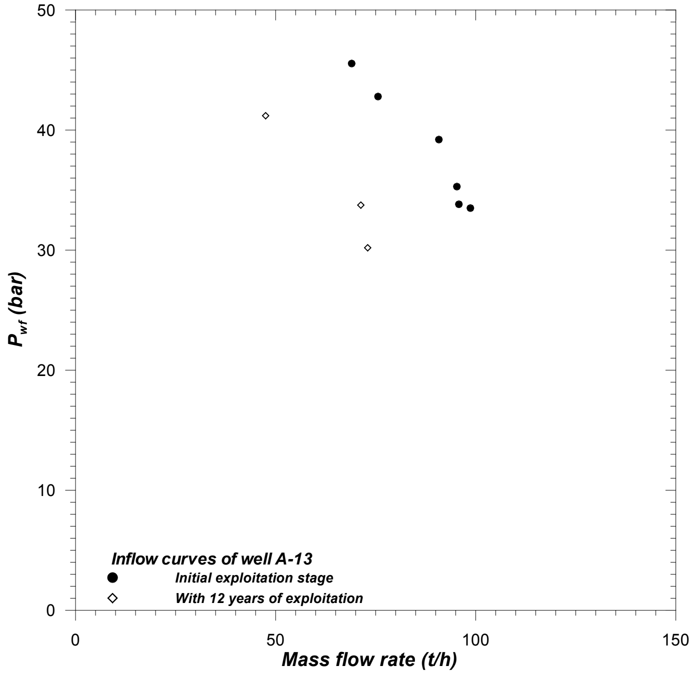

Figure 3. Inflow curves determined at different stages of exploitation of the well A-13 of the Los Azufres, Michoacán, México, geothermal field.

The Decline in Production

The decline of the well productivity is a result of the exploitation processes, which is identified in a graph of flow rate versus time. The common methods of the decline analysis (Fetkovich, 1980) are based in the dimensionless values of time and flow rate. Faulder (1997) extends the applicability of the type-curves for analysis decline, to geothermal reservoirs in steam phase.

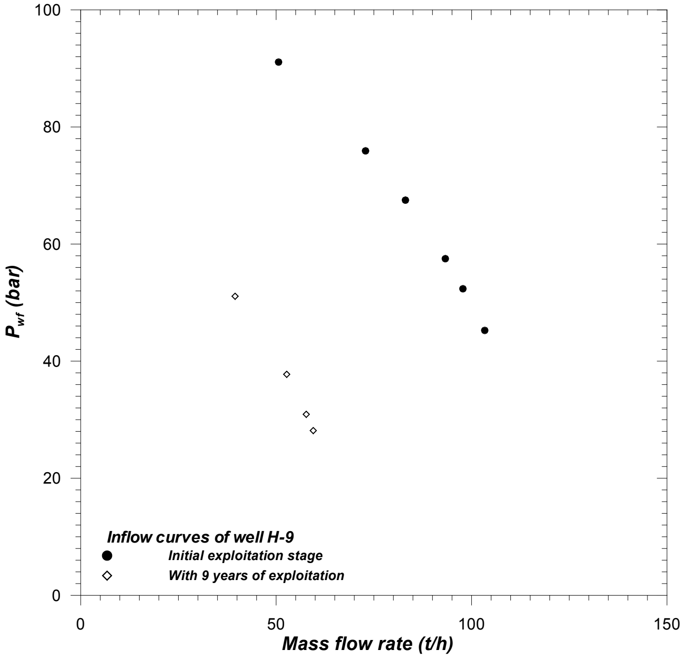

Figure 4. Inflow curves determined at different stages of exploitation of the well H-9 of the Los Humeros, Puebla, México, geothermal field.

However the decline in a well also can be identified from the different characteristics curves (mass flow rate versus wellhead pressure), obtained from the production tests carry out periodically in the wells incorporated to exploitation systems. These tests are a useful tool, because from their results are established and modified the criteria for the design of exploitation of the wells.

In the present work are used the inflow curves, obtained from the production tests carried out in different stages of exploitation of three wells of mexican geothermal fields (Truesdell and Lippmann, 1998; Hiriart and Gutiérrez-Negrín, 1998). Figures 2, 3 and 4 show the inflow curves obtained from the measurements made. From the last three figures it is possible to identify the decline tendency of the productivity, with respect to time. The goal of the present work is to identify the presence of damage effect as manifested in the decline in the productivity of the well.

Damage Determination

Using the Equations (9) and (10), the dimensionless values of each measured point (W, p) were obtained, from the characteristic curve of each well. The results obtained in this step were overlayed on the type curve of the Figure 1. The damage value was determined by the identification of the dimensionless type curve on which the data points lie.

Figures 5 and 6 (overleaf) show the example of the use of the type-curve, using the first two inflow curves of well 101 (shown in Figure 2). The same procedure was applied in the determination of the damage value using the inflow curves of the wells mentioned in this work.

For each case the respective damage values were determined which are shown in Table 1. Also appear the corresponding values of W_{max} and p_r calculated for each stage.

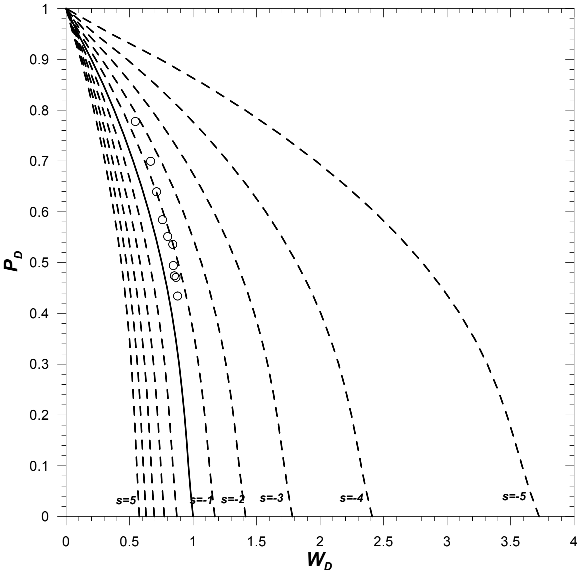

Figure 5. Determination of the damage value in the well 101, using the measurements of the test production, carried out at the initial stage of its exploitation.

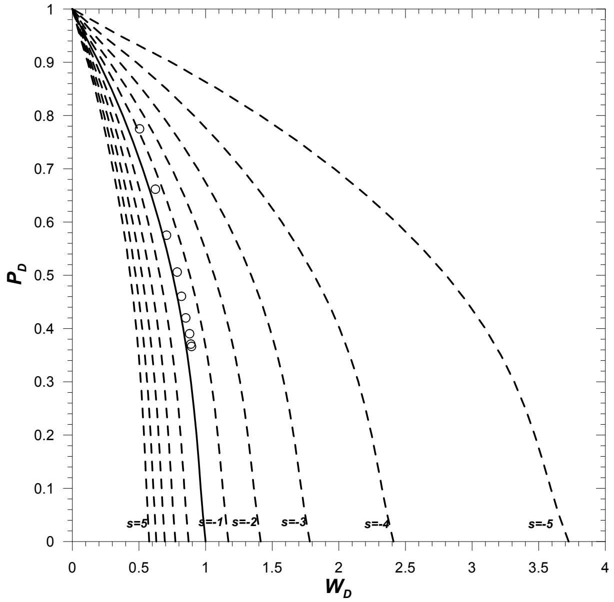

Figure 6. Determination of the damage value in the well 101, using the measurements of the test production, carried out after one year of exploitation.

Results Discussion

The type-curves (Figure 1) obtained from the inflow relationship of Eq. (7) with damage effect, show negative and positive values of the damage. The negative values of the damage indicate the existence of beneficial conditions in a well, such as, after water circulation, during its completion stage, to clean its walls, removing any sediment of the drilling fluid. Other beneficial conditions in the well are due to those caused by interventions of stimulation, fracturing, acidification, etc.

The damage values determined in the analyzed wells show that at the initial stage, there are beneficial conditions. The last situation arises, because the cleaning operations in the stage of well completion, help to recover the natural conditions of the formation.

Table 1. Results of the damage values, obtained at different stages of exploitation of the wells.

Well	Exploitation Period (Years)	Damage Effect (*s*)	W_{max} (t/h)	P_r (bar)
101	0	-1.0	435	130
	1	-0.5	284	121
	4	-0.2	185	77
	6	0	105	67
Az-13	0	-0.5	145	125
	12	4.5	100	110
H-9	0	-0.8	125	118
	9	-0.2	71	77

From the shown graphs it is feasible to determine that the beneficial conditions, in the well, decreased with the exploitation time, and increasing the value of the damage. With the increase of the damage value there is a decrease of the productivity parameters (flow rate and pressure) which are shown in Table 1.

Conclusions

The analysis of the behavior of the inflow curves of wells located in mexican geothermal fields, is shown. Through the analyzed inflow curves, obtained from production tests carried out in different stages of exploitation, can be identified the decline in the well.

The inflow type-curve affected with different damage values was presented. Also was shown the applicability of the inflow type-curve using data measurements of tests production in order to determine the damage in the well.

The obtained results show the feasibility of determining the values of damage effect from the inflow curves, which are obtained from the measurements of production tests that are periodically carried out in wells.

From the analysis results it was found that the exploitation time is an influence factor in the decline of the well productivity and in the increase of the damage value.

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