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Relation between Wells Performance and Damage Effect

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ABSTRACT

We use an alternative technique for determining the damage effect besides the traditional transient pressure tests. This alternative method uses production data of at least three measurements avoiding the necessity of long time as is required for a pressure test to achieve the pseudo steady state. Another of the advantages of this technique is that there is no fluid discharge to the environment and no consumptions of human and material resources. Also, it avoids extracting the wells from production systems, maintaining their continuous operation. One of the main results of the proposed methodology is the reservoir characterization during its operative life obtained from analysis of wells. During the process, inflow curves were used as a technical tool for determining maximum mass flow rate, reservoir pressure and enthalpy. The application of the knowledge of these parameters besides the reservoir behavior, allows for establishing the exploitation designs for each analyzed production stage. The study was carried out using data from representative wells of a Mexican geothermal field in order to characterize them and demonstrate the application of this new methodology. From the identification of the damage, the results can influence the decision making about workovers needed in wells in order to improve their operation.

1. INTRODUCTION

The relationships of the inflow type-curves are characteristic curves of production at bottom-hole conditions. They can be built from the values of both pressure and the measured flow during the production test of a well, or be calculated directly from their characteristic curves of production using a well numerical simulator. The inflow curves and the characteristic curves are unique to each well and vary according to the stage of their productive life. They are also a reflection of the thermophysical characteristic of the formation and of the properties of the fluid in the reservoir.

The application of the inflow curves has been used in hydrocarbon exploitation, in order to establish approaches in the exploitation designs (Evinger and Muskat, 1942; Muskat, 1945; Gilbert, 1954; Gran et al., 1982).

The methods proposed by Fetkovich (1973), Jones et al. (1976), Chu (1988) and Helmy and Wattenbarger (1998) were applied to practical field case studies.

The techniques applied for this type of analysis were adapted from the results of the pressure transient analysis (Muskat, 1945; Van Everdingen and Hurst, 1949; Horner, 1951; Gilbert, 1954; Ramey, 1970; Chu et al., 1980).

Weller (1966) established a method to calculate the behavior of the reservoir decline by using mean of the pressure analysis in the bottom-hole as a function of production. The above mentioned technique comprises the determination of well productivity and the implementation of the methodology proposed by Muskat (1945) and Gilbert (1954).

The development, analysis and application of the first relationships of theoretical curves of the inflow behavior, known as "Inflow Performance Relationships" or "IPR", were done by Vogel (1968). Later on, Standing (1970), Fetkovich (1973), Klins and Majcher (1992), Klins and Clark (1993) and Wiggins (1994), carried out improvements to these first inflow curves. Inflow performance relationships have been used in the petroleum industry for determining the productivity of oil wells (Codeon, 2004) from a single dimensionless IPR. This curve is called a reference curve and relates the dimensionless bottom-hole flowing pressure to the respective dimensionless volumetric flow rate.

The first inflow performance relationship was proposed by Vogel (1968) as follows:

$$\frac{q_o}{(q_o)_{\max}} = 1.0 - 0.2\left(\frac{p_{wf}}{p_e}\right) - 0.8\left(\frac{p_{wf}}{p_e}\right)^2 \tag{1}$$

where q_o, $(q_o)_{max}$, p_{wf}, p_e are volumetric flow rate, maximum flow rate, bottom pressure and static pressure of the reservoir, respectively.

Klins and Majcher (1992) modified the above relation by incorporating the decay factor (n) and the skin damage effect (s) after analyzing information from more than 1340 petroleum wells. The final expression is:

$$\frac{q_o}{(q_o)_{\max}} = M\left[1.0 - 0.295\left(\frac{p_{wf}}{p_e}\right) - 0.705\left(\frac{p_{wf}}{p_e}\right)^n\right] \tag{2}$$

where M is a parameter which incorporates the skin damage effect (s):

$$M = \frac{\ln\left(\frac{r_e}{r_w}\right) - 0.467}{n\left(\frac{r_e}{r_w}\right) - 0.467 + s} = 6.835 \quad (3)$$

where r_e, r_w are the reservoir drainage radius and the wellbore radius, respectively.

The skin effect represents damage presence in a well and is related to reduction of the well's production. A positive value of the skin effect indicates productivity deterioration of the well. A zero value means that the well is in undisturbed state, and negative one indicates improved conditions in the well.

Klins and Majcher (1992) used mean characteristics of the wellbore radius and the drainage of the reservoir in order to determine the value of *M*. They assumed a value of 247 ft as a drainage radius (r_e) and 2 inches as wellbore radius (r_w) and using these values in the original expression of M resulted in constants appearing in Equation (3).

The exponent *n* of Equation (2) is a function of the p_e and the bubble point pressure (p_b), as given by:

$$n = \left[0.28 + 0.72\left(\frac{p_e}{p_b}\right)\right](1.24 + 0.001 p_b) \quad (4)$$

In geothermal engineering, the first geothermal inflow relationship (GIPR) was developed by Iglesias and Moya (1990), where the geothermal fluid was considered as only pure water, whose expression is:

$$\frac{W}{W_{\max}} = 1.0 - 0.6\left(\frac{p_{wf}}{p_e}\right)^2 - 0.4\left(\frac{p_{wf}}{p_e}\right)^4 \quad (5)$$

where W, W_{max} are the produced mass flow and the maximum mass flow (theoretically for $p_{wf} = 0$), p_{wf} and p_e as defined previously.

Subsequently, Moya (1994) obtained the respective dimensionless inflow curve for a binary system H_2O-CO_2, being the expression of the mass productivity as follows:

$$\frac{W}{W_{\max}} = 1.0 - 0.256\left(\frac{p_{wf}}{p_e}\right) - 0.525\left(\frac{p_{wf}}{p_e}\right)^2 - 0.057\left(\frac{p_{wf}}{p_e}\right)^3 - 0.162\left(\frac{p_{wf}}{p_e}\right)^4 \quad (6)$$

The binary model was applied to cases of Mexican geothermal fields by Moya et al. (1995, 1997, 1998). The obtained results agree very well with measured data and from these results it was feasible to obtain output curves. The inflow curves were validated by Iglesias and Moya (1998) through comparison with measurements at bottom-hole conditions. Furthermore, the methodology was also used for determining the permeability formation (Moya et al., 2001; 2003). Later on, Montoya (2003) obtained an expression, assuming the fluid to be a ternary mixture H_2O-CO_2-$NaCl$ with salinity less than 5,000 ppm, as follows:

$$\frac{W}{W_{\max}} = 0.999 - 0.436\left(\frac{p_{wf}}{p_e}\right) - 0.537\left(\frac{p_{wf}}{p_e}\right)^2 + 0.694\left(\frac{p_{wf}}{p_e}\right)^3 - 0.715\left(\frac{p_{wf}}{p_e}\right)^4 \quad (7)$$

An inflow relationship with salt content up to 30,000 ppm in the liquid phase is proposed by Meza (2005).

$$\frac{p_{wf}}{p_e} = 1.0 - 0.619\left(\frac{W}{W_{\max}}\right) + 1.45\left(\frac{W}{W_{\max}}\right)^2 - 5.476\left(\frac{W}{W_{\max}}\right)^3 + 7.605\left(\frac{W}{W_{\max}}\right)^4 - 3.955\left(\frac{W}{W_{\max}}\right)^5 \quad (8)$$

Changing variables to obtain the equation on the form W / W_{max} instead of p_{wf} / p_e, as appears in Equation (8), was done by Aragón-Aguilar (2006) and the expression is:

$$\frac{W}{W_{\max}} = 1.0 - 0.4399\left(\frac{p_{wf}}{p_e}\right) + 1.1658\left(\frac{p_{wf}}{p_e}\right)^2 - 4.0372\left(\frac{p_{wf}}{p_e}\right)^3 + 3.6697\left(\frac{p_{wf}}{p_e}\right)^4 - 1.3782\left(\frac{p_{wf}}{p_e}\right)^5 \quad (9)$$

The inflow relationship considering the fluid as a ternary mixture H_2O-CO_2-$NaCl$ with high salinity (greater than 30,000 ppm of $NaCl$) and high temperature (350°C) was proposed by López-Blanco (2011).

$$\frac{W}{W_{\max}} = 1.0 - 0.443\left(\frac{p_{wf}}{p_e}\right) - 0.4738\left(\frac{p_{wf}}{p_e}\right)^2 + 0.803\left(\frac{p_{wf}}{p_e}\right)^3 - 1.155\left(\frac{p_{wf}}{p_e}\right)^4 + 0.271\left(\frac{p_{wf}}{p_e}\right)^5 \quad (9)$$

In order to incorporate the damage effect into the reference curve of Equation (9), it is appropriate to mention the proposed method by Klins and Majcher (1992). In order to determine the values of the constants applicable to geothermal systems, a research was carried out about the characteristics of the pipes' production and mean dimensions of the different geothermal reservoirs of the world. The obtained results helped to establish the values of r_w of 2 inches and r_e of 750 ft. and taking into account previous values, the equation to determine the value of M can be given by the next expression:

$$M = \frac{7.75}{7.75 + s} \quad (10)$$

This factor affects the reference curve given by Equation (9), which is function of p_{wf}, p_e and skin damage.

$$\frac{W}{W_{\max}} = M\left[1.0 - 0.443\left(\frac{p_{wf}}{p_e}\right) - 0.4738\left(\frac{p_{wf}}{p_e}\right)^2 + 0.803\left(\frac{p_{wf}}{p_e}\right)^3 - 1.155\left(\frac{p_{wf}}{p_e}\right)^4 + 0.271\left(\frac{p_{wf}}{p_e}\right)^5\right] \quad (11)$$

Equation (11) is the proposed reference curve for geothermal reservoir with damage effect. Using variables in dimensionless form:

$$W_D = \frac{W}{W_{\max}} \quad (12)$$

$$p_D = \frac{p_{wf}}{p_e} \quad (13)$$

Thus, the dimensionless form of Equation (11) is as follows:

$$W_D = M\left[1.0 - 0.443(p_D) - 0.4738(p_D)^2 + 0.803(p_D)^3 - 1.155(p_D)^4 + 0.271(p_D)^5\right] \quad (14)$$

A plot of Equation (14) is shown in Figure 1 for skin damage values between -4 and +6.

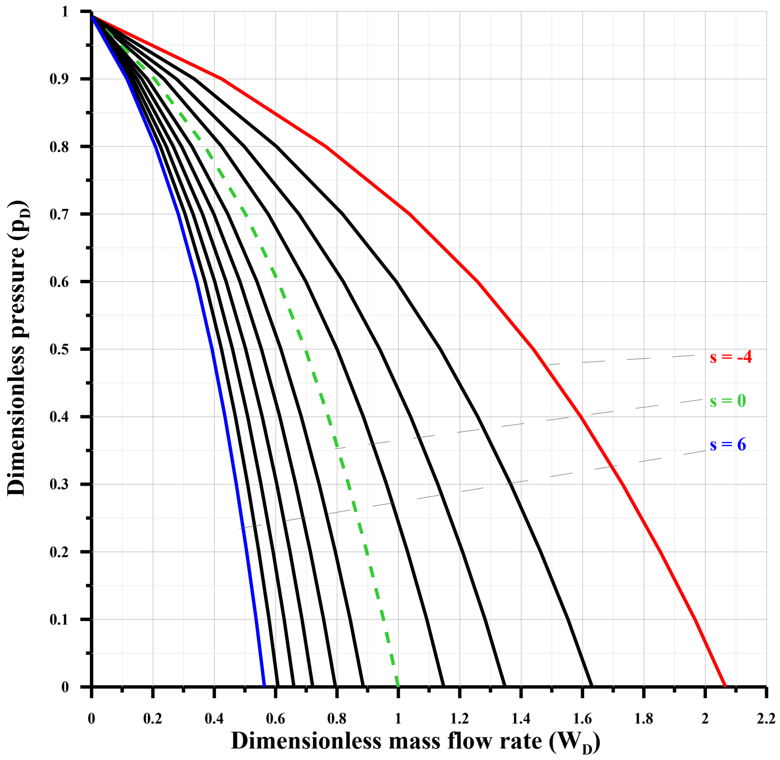

Figure 1: Type-curve for different skin damage values (*s*) obtained from Eq. (14).

The practical application of this type-curve is focused on determining the damage effect values in wells, using dimensionless parameters (W_D, p_D) obtained from their production measurements.

2. METHODOLOGY

The proposed general methodology to determine the damage in wells by using geothermal type-curves with damage effect [Equations (11) and (14)] is shown in the flow diagram in Figure 2. The methodology makes use of the SISTCURV (Moya and Uribe, 2000; Moya et al., 2003), which is a computer program that uses measured data (pressure, flow) of a production test in a geothermal well (Aragón-Aguilar et al., 2008a; 2008b).

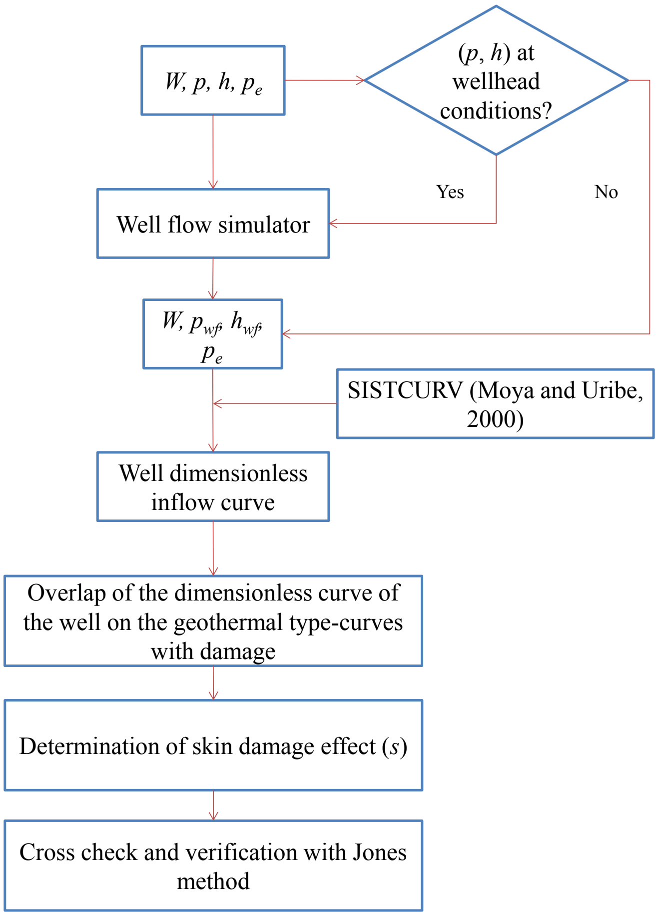

Figure 2: General methodology employed to determine the damage effect in a geothermal well using the proposed geothermal type-curves with damage.

According to Figure 2, in general terms the methodology employed in this study can be described as follows:

1. The input data correspond to the data of a production test and include the mass flow rate (*W*), the flowing pressure and enthalpy (p, h), and the static reservoir pressure (p_e).
2. If data is available for wellhead conditions, then a well flow simulator is used to obtain the bottom-hole flowing conditions (p_{wf}, h_{wf}).
3. The dimensionless inflow curve of the well is determined from the reference curve (Equation (5)) employing the computational system SISTCURV (Moya and Uribe, 2000; Moya et al., 2003).
4. The dimensionless inflow curve of the well is overlapped on the geothermal type-curve with damage effect shown in Figure 1. The damage effect (s) will be obtained from the best overlap of both curves.
5. The method proposed by Jones et al. (1976) is used to corroborate the value of the determined damage effect using the proposed methodology.

The Jones (et al., 1976) method has been applied to determine formation conditions at the end of the perforation as well as at any stage in the life of the well. It was designed primarily for application in oil wells, but, to date, such application has been extended to geothermal wells. The method is useful in the identification of pressure losses for turbulent flow (there are restrictions in the wells feeding area related to the damage) (Aragón-Aguilar et al., 2008a; 2008b). The method requires at least three pairs of measured data (W, p) and the procedure is as follows:

Calculate the value $(p_e\text{-}p_{wf})/q$ for each of the different measurements. This value represents the inverse value of the productivity index J, whose expression is:

$$J = \frac{q}{\Delta p} = \frac{q}{p_e - p_{wf}} \tag{15}$$

Obtain a graph of $(p_e\text{-}p_{wf})/q$ versus q, and later fit the calculated values to a right line equation, determining the values of the intersection to origin (b value) and the slope (m), according to Equation (16).

$$p_e - p_{wf} / q = mq + b \quad (16)$$

If *b* value is less than 0.05 there is no damage in the well. Inversely, if *b* value is greater than 0.05 there is damage in the analyzed well. The Jones (et al., 1976) method can also be applied to identify the presence of turbulent flow in the wellbore by calculating *b'* value, using next expression:

$$b' = b + mq_{\max} \quad (17)$$

If the value of the ratio b'/b is $b'/b < 2.0$ the turbulent flow is light or null at the interface wellbore-reservoir. For values of *b* less than 0.05 and *b'/b* greater than 2, the poor productivity could be because the area for the flow is not enough. Under last condition, the appropriate solution is to improve the exploitation zone by making the well deeper (Aragón-Aguilar et al., 2008a; 2008b).

3. RESULTS

The methodology described above was applied to data from six wells of a Mexican geothermal field. From the production measurements (W, p) taken at the wellhead, bottom-hole flowing pressure (p_{wf}) was determined using well flow simulators. The Mexican geothermal field used for this study is highly fractured and of volcanic origin. It is important to mention that the field is a tectonic regional system and recent stress generated normal faults in E-W direction. Last stress release resulted in creation of ancient faults, which are crossed by the majority of the production wells. Therefore it is believed that these faults act as geothermal fluid conduction, controlling the majority of thermal hot springs.

Due to that there is no methodology for verifying the presence or absence of the damage effect, it was found appropriate to apply the methodology of the turbulence analysis (Aragón-Aguilar et al., 2008b) using production measurement data. This methodology allows diagnosing the presence or absence of the damage effect and its use has shown to be successful. This methodology was developed to be applied on oil wells and thus the application on geothermal wells, to date, is too scarce. The Jones method is used to identify the loss of pressure due to turbulent flow caused by the presence of damage at the interface well-reservoir (Aragón-Aguilar et al., 2008b).

The methodology was used for each well, using data from their production tests, carried out at different stages of the operative life, where the parameter values at reservoir conditions were calculated as well as the corresponding dimensionless values (W_D, p_D) using Equations (12) and (13). The dimensionless value pairs are graphed on the type-curve with damage effect (Figure 1) for high salinity and temperature.

From comparison of the dimensionless values of the well to the type-curve, the damage effect is determined as shown in Figure 3. In this work, we presented production measurement data for well E. However, a similar process was applied in all analyzed wells and the results are shown in Table 1.

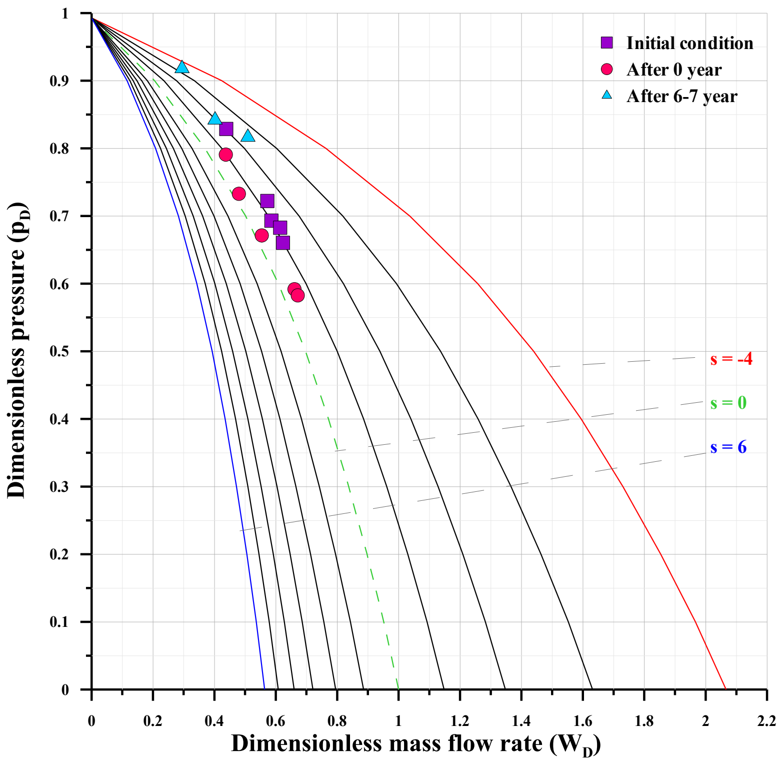

Figure 3: Obtention of the damage effect values, using the type-curve with damage effect, high salinity, high temperature and production data for well E.

Table 1 shows the main values obtained in this work, which are useful for well characterization. The different times of operative life of each analyzed well are shown in this same table. Similarly the characterization parameters (W_{max}, p_e) of the reservoir, the damage effect (*s*) and the parameters of Jones et al. (1976) are shown. From Table 1 a correlation can be observed between the columns of the damage effect, Jones et al. (1976) parameter and the diagnosis about presence or absence of damage (Figure 4).

Table 1: Damage values and characterization parameters obtained with the methodology described in this work using production measurement data of analyzed wells.

Well	Time operative life (years)	p_e (bar)	W_{max} (t/h)	Damage effect (s)	Jones et al. Parameter	Diagnosis
A	0	60	145.3	-3.9	0.005	No damage
	3	55	129.1	-3.5	0.014	No damage
	19	50	41.8	-1.9	0.039	No damage
B	0	60	240.3	-0.2	0.010	No damage
C	0	220	288.5	-0.3	-0.026	No damage
D	0	62	71.1	-1.0	0.041	No damage
	11	60	70.2	0.1	0.060	Damage
E	0	52	100.5	-1.0	0.032	No damage
	0	58	93.9	-0.5	0.043	No damage
	7	43	133.6	-2.2	0.033	No damage
F	0	70	204.7	-3.1	0.016	No damage

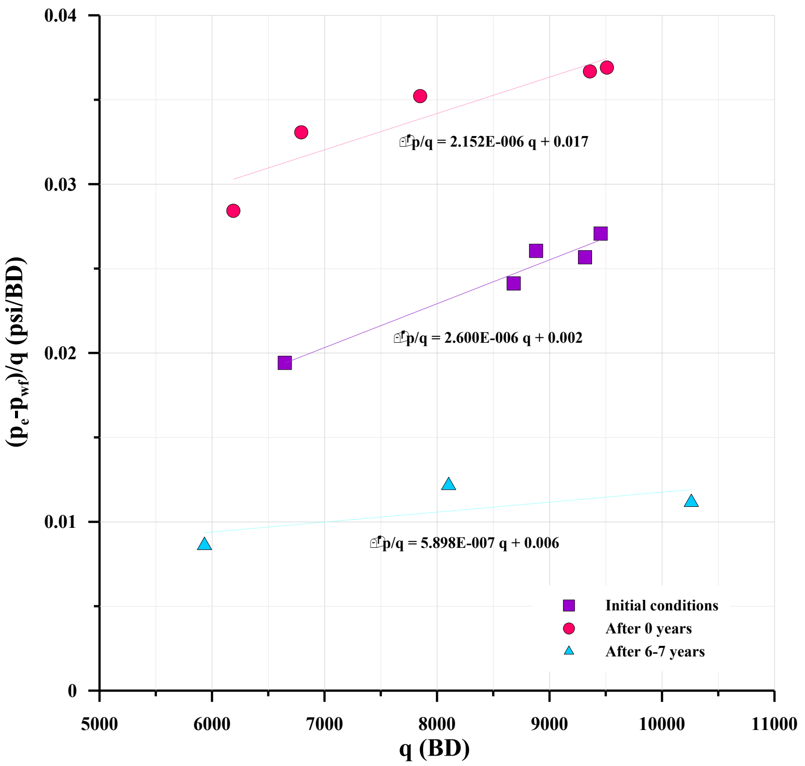

Figure 4: Application of Jones et al. (1976) methodology for diagnosing damage presence in well E.

Using the described methodology it can be observed that negative values of the damage effect were obtained in all cases except one. As mentioned before, the behavior of the damage effect is a function of the reservoir characteristics and therefore can be related to the decline of a well's productivity. The obtained values of the damage effect in each well show a behavior corresponding to different stages of their operative life.

It is important to identify that the values of damage effect obtained in wells A, D and E change as a function of the exploitation time. Also it is assumed that the damage effect values change due to different jobs applied in the well, such as cleaning, repairing, stimulating, fracturing, among others. This can be observed in the behavior of obtained values of the damage effect in well E whose change indicates improvement. The change to positive values of damage effect in well D indicates decline in its productivity.

The obtained parameters from Jones et al. method, shown in Table 1, indicate that in the majority of the cases *b* values are less than 0.05, which is related to beneficial conditions. From the results a consistency can be identified in the obtained values through the application of both methodologies.

The slight increase in the calculated value of the damage effect in well D is related to decline in its productivity. The main objective of the inflow relationships in the reservoir and production engineering is focused on practical applications such as productivity diagnosis of the wells, exploitation designs, reserves calculation etc., (Aragón-Aguilar et al., 2008b). As can be seen, the obtained values of the damage effect correspond to wells during their production stage, which is useful when analyzing their performance. On the other hand, taking into account that the behavior of the damage effect is related to the productivity decline, it is feasible to use both parameters for reservoir characterization.

The behavior of the obtained results supports the argument of the influence that structures (barriers, faults, fractures etc.) can have on the flow control in volcanic reservoirs (López-Blanco et al., 2012).

4. CONCLUSIONS

The process for obtaining the type-curve with damage effect for reservoirs with high salinity, high temperature and its application to cases of a Mexican geothermal field, was shown. From the obtained results it is possible to identify the decline trend using the results of the damage effect in analyzed wells. The presence of the damage effect was validated using an alternative methodology which allows the presence of damage to be qualitatively determined and the obtained results are congruent between them. Due to the obtained results with the methodology applied in the analysis of the field behavior, it can be assured that this methodology useful in reservoir characterization. Through this work it was found that the knowledge of the damage effect using production measurements is a useful technical tool in the criteria definition for establishing exploitation designs.

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