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Original paper

# Declining productivity in geothermal wells as a function of the damage effect

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**Resumen**

La curva-tipo geotérmica afectada por daño sirve para determinar el efecto de daño en un pozo y para caracterizarlo. Esta metodología puede ser aplicada para determinar el efecto del daño en los pozos que no pueden ser retirados de la explotación continua. Comúnmente se emplean los análisis de las pruebas transitorias de presión, cuya ejecución es tardada. En los pozos analizados, el efecto de daño aumenta con su tiempo de explotación y está relacionado con el deterioro en la producción. El conocimiento del daño ayuda a la toma de decisiones acerca de las operaciones a aplicar en el pozo con el objeto de mejorar su productividad.

Palabras clave: factor de daño, productividad, declinación de la producción, diseño de la explotación, campo geotérmico, Los Azufres, Cerro Prieto.

**Abstract**

The inflow curve may be used to determinate the damage effect and wellbore characterization in geothermal fields. The methodology can be applied for determining damage effect in wells that cannot be retired from continuous exploitation. The skin or damage effect is usually estimated from transient pressure tests which require time. It was found that the damage effect in the wells increases with exploitation time and is related with deterioration of production. Knowledge of damage is needed for taking decisions about operations on the well for enhancement of productivity.

Key words: skin factor, damage effect, productivity, production decline, design exploitation, geothermal field, Los Azufres, Cerro Prieto.

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## Introduction

Production evaluations of geothermal wells are carried out periodically to characterize the well, and to establishing criteria for operation during continuous exploitation. Drawdown pressures from the reservoir to delivery points are calculated using nodal analysis (Flopetrol Johnston-Schlumberger, 2008). Figure 1 shows a schematic diagram of the pressure at different points $p_e$ is the static pressure, $r_e$ is the drainage radius, $p_{wf}$ is the pressure at bottom-hole, $r_{wf}$ is the radius of the well, $p_{wh}$ is the pressure at well head and $p_s$ is the pressure at the inlet of the separator.

Abnormal decreases in well pressure are caused by the increase of flow during output tests (Evinger and Muskat, 1942; Horner, 1951; Matthews *et al*., 1954). Evinger and Muskat (1942) showed that the abnormal behavior in the drawdown pressure is related to deterioration of production.

Knowledge of the skin effect (Evinger and Muskat, 1942; Horner, 1951; and Ramey, 1970) during production is useful for taking decisions about operations such as cleaning, repairs, stimulations, etc.

The skin effect is synonymous to damage in a well and reduction of its production. A positive value of the skin effect indicates deterioration of the well. A zero value means that the well is in undisturbed state, and a negative one indicates improved conditions in the well. A decrease in production is a consequence of damage.

Vogel (1968) proposed an inflow performance relationship as follows:

$$Q_D = 1.0 - 0.2\left(p_D\right) - 0.8\left(p_D\right)^2 \qquad (1)$$

where $Q_D = q/(q_o)_{max}$ is the dimensionless mass flow and $p_D = p/p_e$ is the dimensionless pressure.

Other authors, (Standing, 1970; Klins and Majcher, 1992; Iglesias and Moya, 1998; Moya *et al*., 1998) proposed inflow performance relationships.

## Damage effect related with production decline

Figure 2 shows the descriptive behavior of the pressure in the reservoir without skin ($p^*_{wf}$) and with skin ($p_{wf}$). It can be observed an additional drawdown of the pressure under presence of damage.

For incorporating damage effect into the inflow relationship, Aragón (2006); Aragón *et al*. (2008a) and Aragón *et al*., (2008b) proposed following expression considering the main characteristics of geothermal systems:

$$M = \left( \frac{\ln \frac{r_e}{r_w} - 0.6603}{\ln \frac{r_e}{r_w} - 0.6603 + s} \right) \qquad (2)$$

where $r_e$ is the reservoir radius, $r_w$ is the wellbore radius and s is the damage effect. The main considerations were the variation of the radii of the wells ($r_w$) between 2 and 3.5 inches (0.0508 and 0.0889 m). Due to the uncertainity of the drainage radius value ($r_e$), a sensitivity analysis of the behavior of the M factor against damage

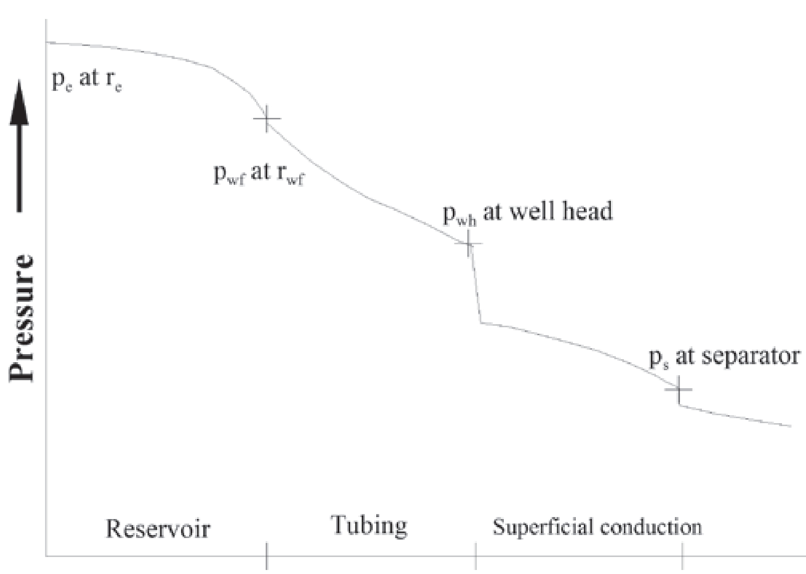


**Figure 1.** Behavior of the pressure at different points along the travel of the fluid between the reservoir and the final delivery.

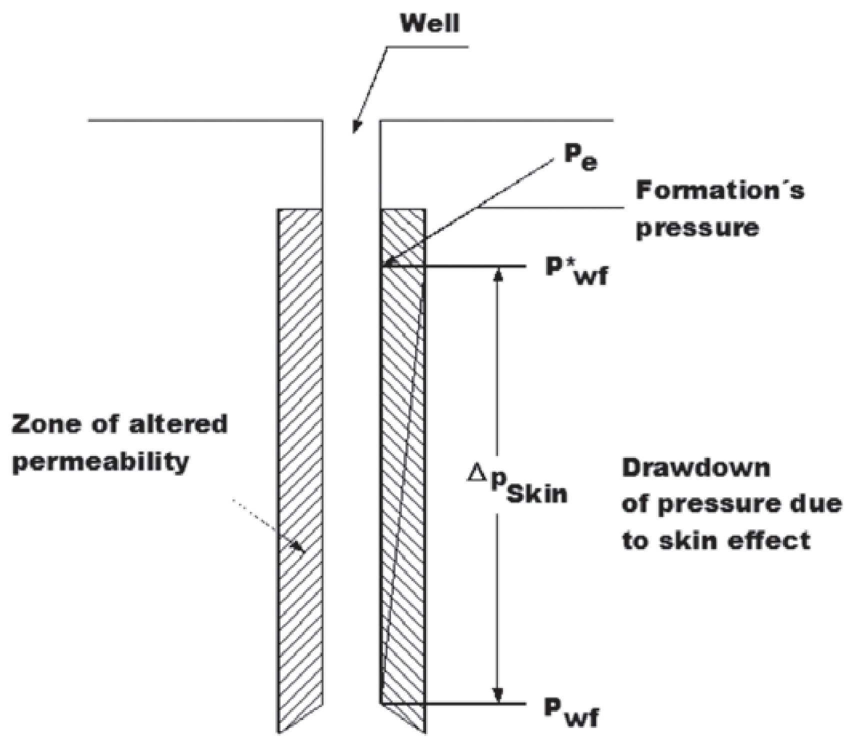


**Figure 2.** Pressure distribution in the reservoir for cases with and without damage effect.

effect for different values of $r_e$ was done and the results are shown in Figure 3. The value of well radius ($r_w$) used in this equation is the common of the tubing in geothermal systems of 3.5 inches (0.0889 m).

## Geothermal inflow performance relationships affected by damage

The general expression of geothermal inflow relationship affected by damage and considering the fluid as ternary mixture (Montoya, 2003; Meza, 2005) $H_2O$-$CO_2$-NaCl is:

$$p_D = M\left\{0.993 - 0.16(W_D) - 2.08(W_D)^2 + 3.95(W_D)^3 - 2.70(W_D)^4\right\} \qquad (3)$$

The graphic expression of the equation (3) is a family of curves, each one of these, representing different damage values and is called as the geothermal inflow type-curve affected with damage. The type curve is shown in Figure 4 and is being applied for determining the damage effect in wells using their production data measured at different flow rates.

For using the measured data of the well with this type-curve it is necessary to adequate them to bottom-hole conditions. It is achieved through the use of a flow simulator.

## The geothermal inflow type-curve used with practical cases

For showing that the methodology can be applied in any geothermal field, two representative Mexican fields were selected; Los Azufres geothermal field which is located inside the Mexican Neovolcanic Belt, (volcanic formation) and the Cerro Prieto geothermal field as an example of sandy formation. The location of both fields is shown in Figure 5. Examples of how to use the geothermal inflow type curve are shown using data of production wells of these two fields. Representative wells of both geothermal fields were chosen.

*Case 1*

The described methodology for determining the value of the damage effect in geothermal wells, was applied using production data (Iglesias *et al*. 1985; Hiriart and Gutiérrez-Negrin, 1998) of well A-13 at Los Azufres, geothermal field. The analyzed well of this field was chosen due to its representative characteristics of the field. The

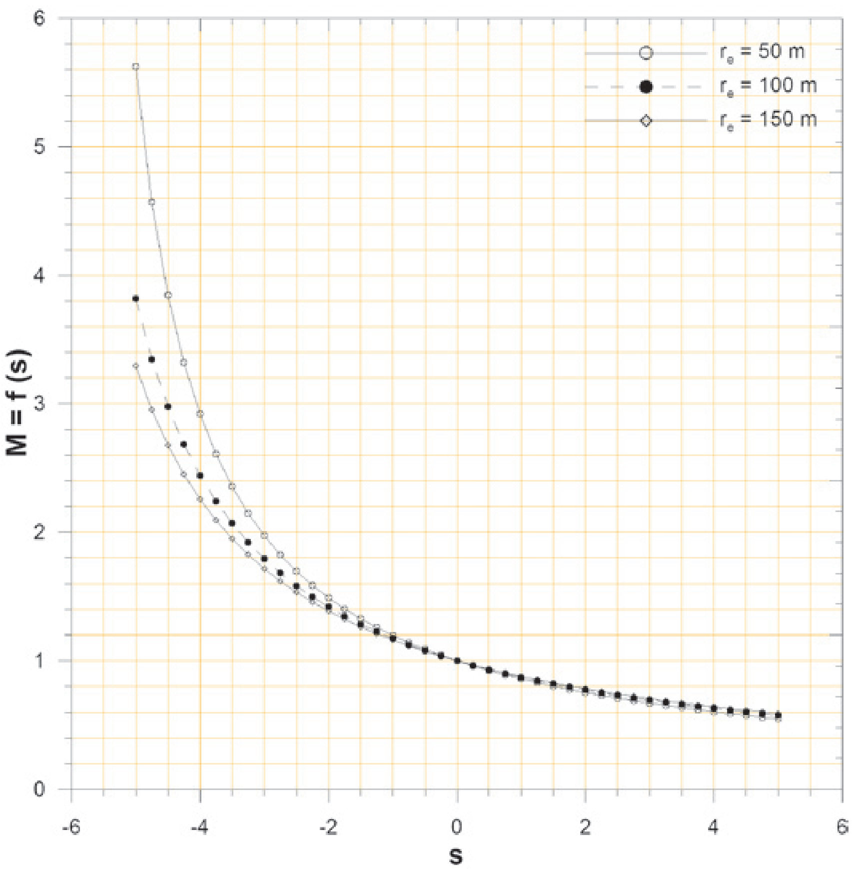


**Figure 3.** Performance of the $M$ factor as function of the damage value ($s$), for different values of the reservoir drainage radius ($r_e$).

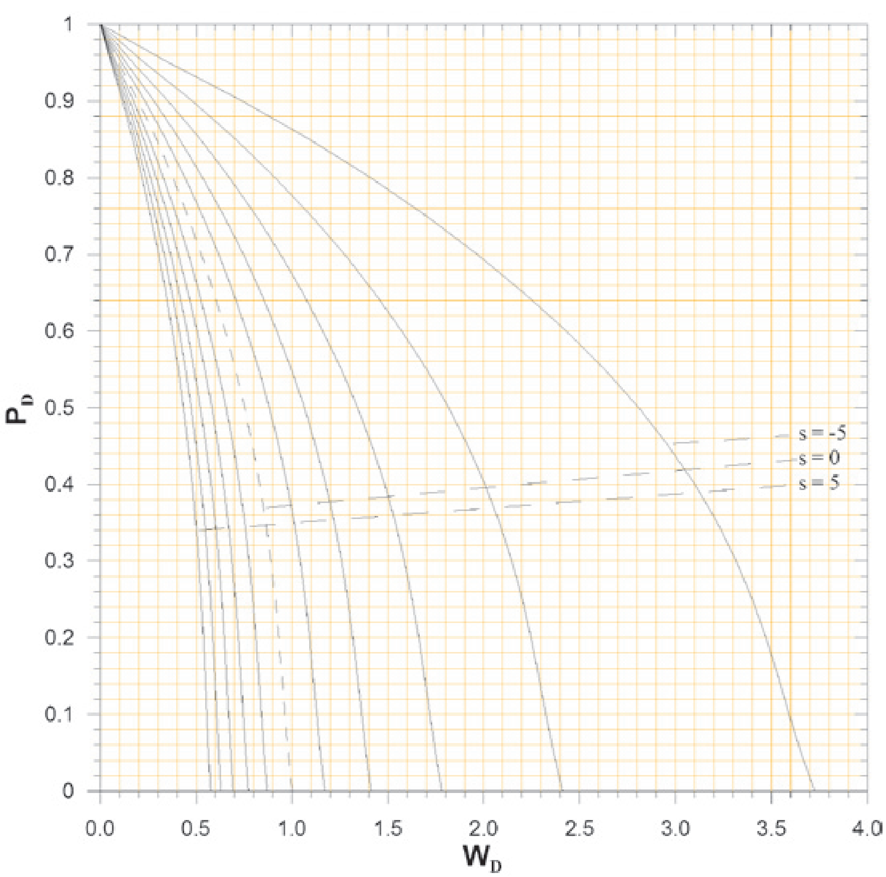


**Figure 4.** Geothermal inflow type curves for determining the damage effect in wells, using data of production measurements.

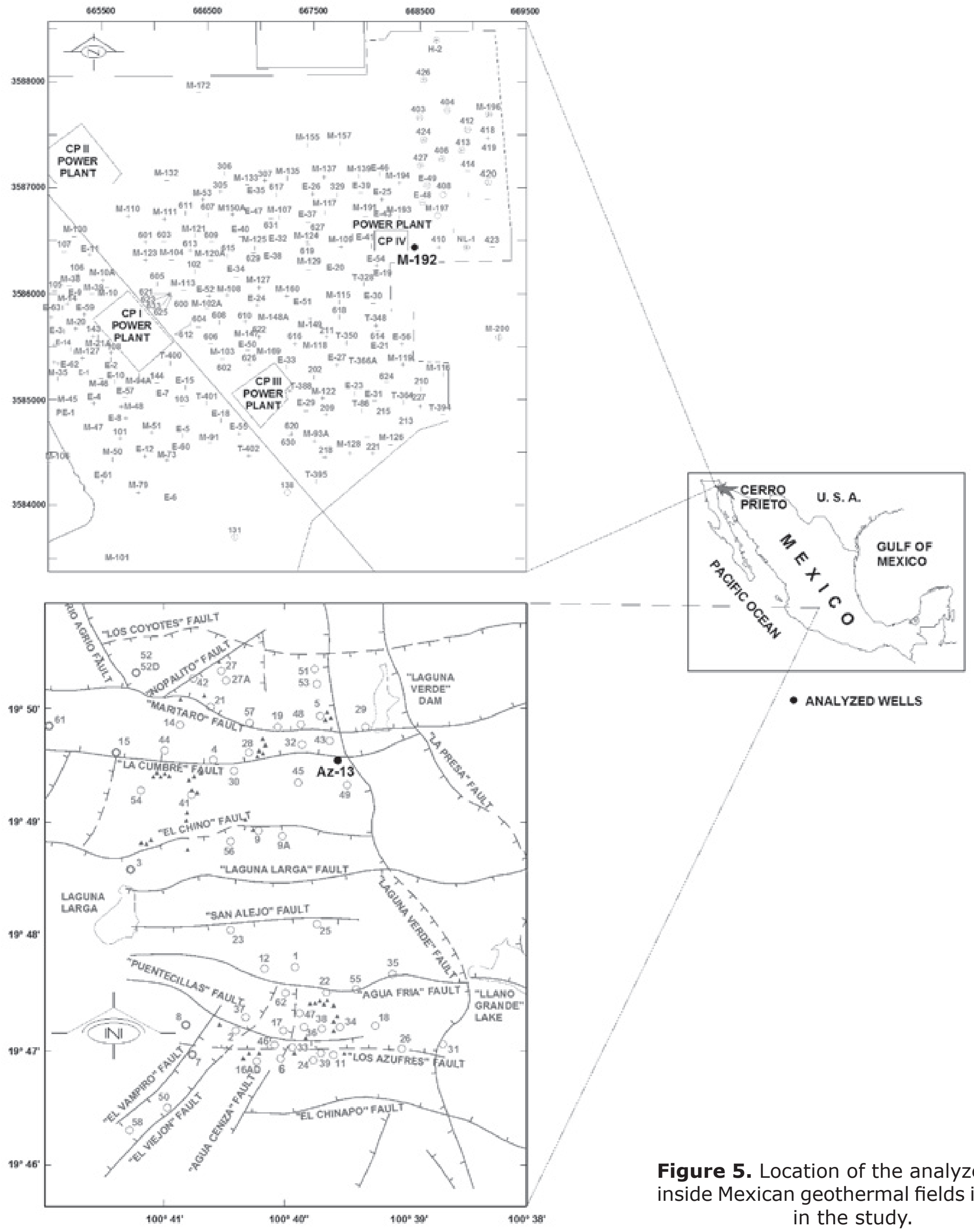


**Figure 5.** Location of the analyzed wells inside Mexican geothermal fields involved in the study.

production of this well is mainly a two phase flow. The selected data correspond to initial conditions and after different times of continuous exploitation. Through the knowledge of the initial conditions in the well, and its subsequent behavior it was feasible to identify its decline due to the continuous exploitation.

Figure 6 shows the characteristic production curves of the well at initial conditions and after different times of its continuous exploitation. The measured data were taken at wellhead conditions, so that the well flow simulation program (PBPower, 2005) was used to determine the variable values at bottom-hole conditions.

Dimensionless values of pressure and flow rate were calculated for each one of the measurements done during the output tests. Therefore by applying the methodology, the value of the damage, is determined by identifying that curve where the dimensionless values ($W_D$, $p_D$) are located. Figure 7 shows the graphs using the geothermal inflow type-curve and the dimensionless data sets of three output tests carried out in this well.

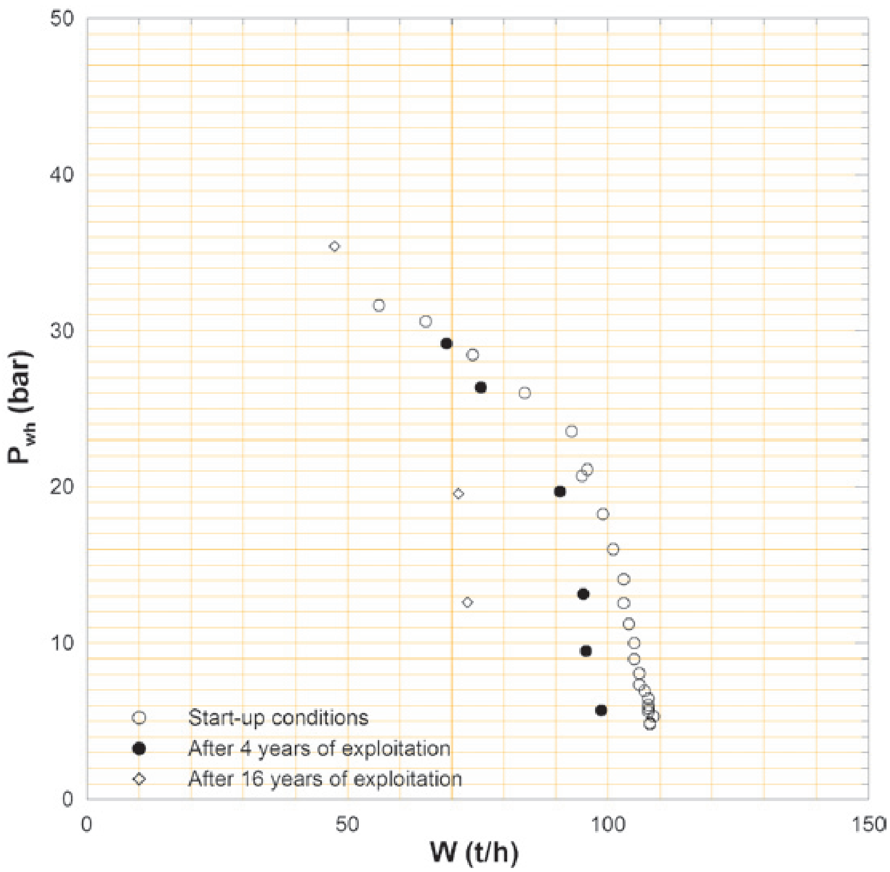


**Figure 6.** Production characteristic curves of well A-13 of the Los Azufres geothermal field, at its initial conditions, and after 4 and 16 years of continuous exploitation.

From last figure, it can be noticed that the determined values of the damage effect, is -2.1 for initial conditions, of -1.9 after 4 years and of 0.5 after 16 years of continuous exploitation. The decrease both in pressure ($p$) as in mass flow ($W$) were determined by year, taking into account the interval times between measurements. The found negative values of $\Delta p$ and $\Delta W$, are related to the decline productivity of the well.

*Case 2*

Production measurements of well M-192 (Ribó, 1989) taken as representative for the Cerro Prieto geothermal field were analyzed following this methodology. This well is located in the area of CP IV zone (Figure 4). The analysis was carried out at initial conditions and after six years of continuous exploitation. The output characteristic curves of this well are shown in Figure 8. The determination of the damage effect in this well is shown in Figure 9. As can be seen in this figure, the determined damage effect in this well was of -3.6 for initial conditions and of 1.5 after six years of continuous exploitation.

Table 1 summarizes a correlative analysis of the behavior of the pressure, mass flow rate and damage effect, respect to exploitation time of the analyzed wells.

**Discussion results**

From a sensibility analysis of Equation (2), it is possible to deduce that the values of the reservoir's drainage radius ($r_e$) do not produce great variations of the $M$ factor.

For initial conditions in the wells, the damage value is negative, mainly due to the washing operations applied at their completion stage. The negative value of the damage effect is equivalent to obtain beneficial conditions in the well. Accordingly, it was found there is relation between the obtained damage values and the time of operative life of the well at date of the production measurements. It seems that in the analyzed wells, the values of the damage effect increase due to their decline. Through comparison of the characteristic production curves obtained at different stages of the productive life of the well, if can be noticed the decline in its productive properties (see Figures 6 and 8). In summary it can be seen the decrease in the productive characteristics of analyzed wells, as a function of their exploitation time.

The obtained results (Table 1), indicate that damage effect is related with the well decline. It is important to emphasize that both analyzed wells show that while the damage effect increases, their productive characteristics diminish. The last two columns of Table 1 show the yearly decrease of pressure and mass flow rate and as mentioned before, these variables decrease with exploitation time.

**Table 1.** Behavior of the production parameters analyzed through the production tests carried out at different stages in well A-13 of Los Azufres geothermal field and in M-192 of Cerro Prieto geothermal field.

| Well | Production time (years) | $p_{wf}$ (Bar) | $W_{max}$ (t/h) | $S$ Damage | $-\Delta p$/year (Bar/yr) | $-\Delta W$/year (t/h)/yr |
|---|---|---|---|---|---|---|
| | 0 | 58.7 | 110 | -2.1 | | |
| A-13 | 4 | 55.1 | 103 | -1.9 | .9 | 1.8 |
| | 16 | 52.2 | 86 | 0.5 | .73 | 4.3 |
| M-192 | 0 | 315 | 475 | -3.6 | | |
| | 6 | 207 | 350 | 1.5 | 18 | 20.8 |

It is important to take into account, the magnitude of the change of the production variables in Los Azufres and in Cerro Prieto geothermal field. So, the mean mass flow rate ($W$) in Cerro Prieto wells is twice higher than that of wells in Los Azufres. Similarly the mean value of bottom-hole flowing pressure ($p_{wf}$) is more than three times higher in Cerro Prieto wells, than at Los Azufres wells.

The values of the damage effect, of the analyzed wells, increase with the exploitation time (Figures 7 and 9). In general, the results of the values of the calculated damage effect show an increase, which is related with its exploitation period (Table 1). Taking the total of analyzed period time of each well, it can be found that yearly variation of the damage effect for the well of Los Azufres is of 0.1625, however for the well of Cerro Prieto is of 0.85.

## Conclusions

From the study carried out the main conclusions are:

The obtained results support the feasibility for apply this methodology in geothermal fields with any rock formation type.

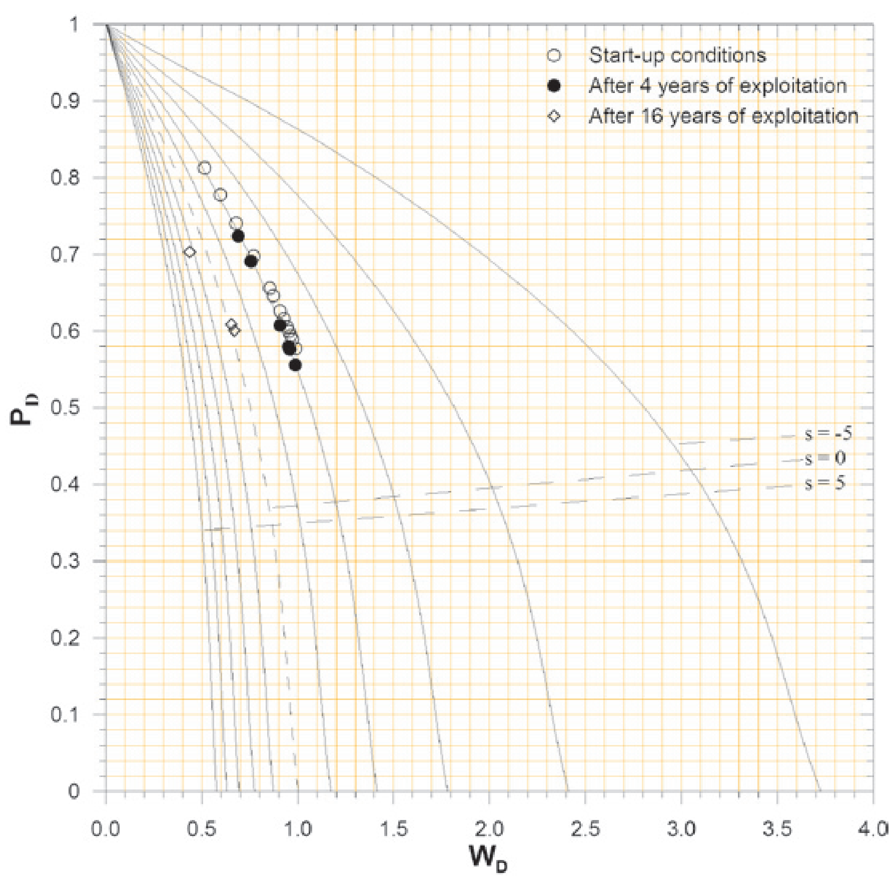


**Figure 7.** Application of the geothermal inflow type-curve, for determining the damage effect using data set of output tests, taken at different exploitation times, in the well A-13 of the Los Azufres México geothermal field.

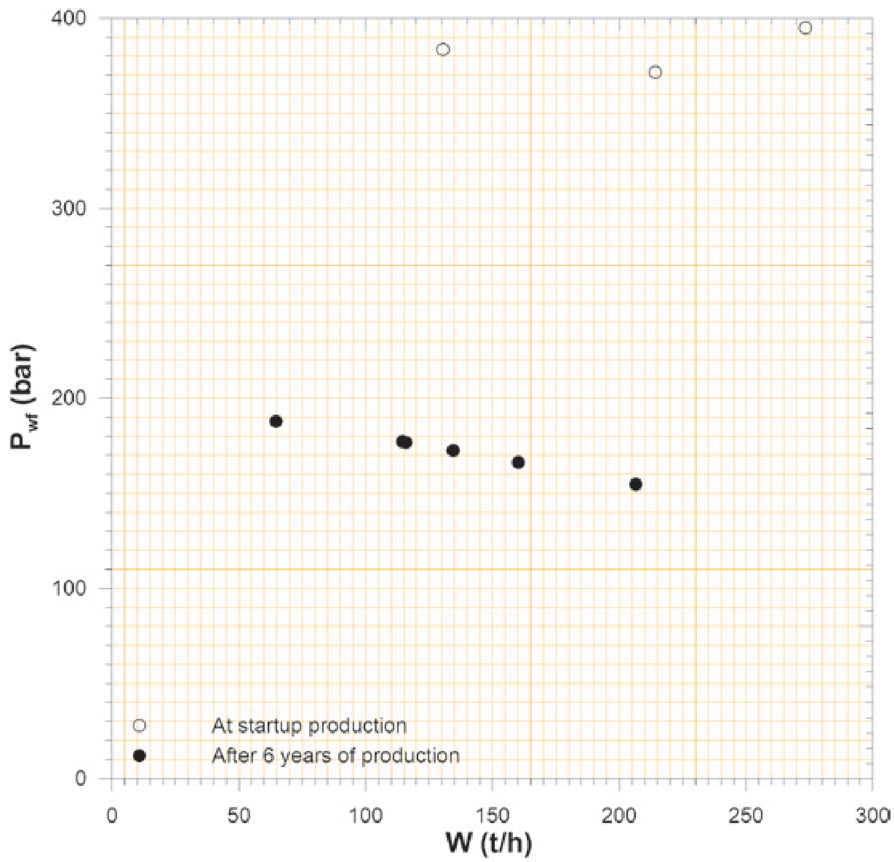


**Figure 8.** Production characteristic curves of well M-192, taken at its initial conditions and after six years of continuous exploitation time.

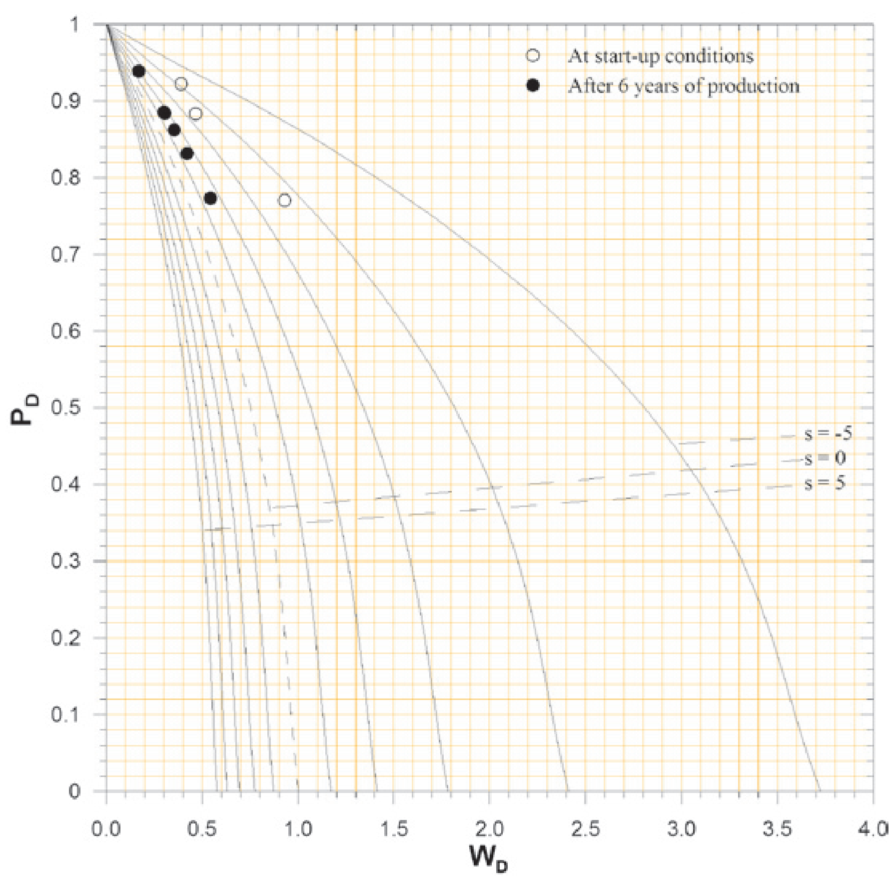


**Figure 9.** Determination of the damage effect, from the use of the geothermal inflow type curve with the measurements carried out in well M-192 at its initial conditions and after six years of continuous of continuous exploitation.

The results indicated that inflow performance relationships can be used as a technical tool for characterizing the wells productivity at initial conditions and at different stages of their operative life.

According with the obtained results, the geothermal inflow type curve can be taken as an alternative tool for determining the damage in wells that do can not be retired from the continuous system exploitation.

The numerical value of the damage effect determined in the analyzed wells increases as function of the exploitation time, being it an indicative parameter of the diminution of the productive characteristics of the well.

The knowledge of the damage effect allows support to decisions in order to apply the appropriate remediation operations in wells, such as cleanings, repairs, stimulations, etc., for enhancement of their productivity.

The applied methodology allows the characterization of the decline of production parameters ($W$, $p_e$) of wells. This knowledge is useful for taking the best decisions in the establishment of the wells exploitation designs.

An important topic for future research in this area is the study of yearly behavior of damage effect found in the well of Cerro Prieto that differs greatly from that determined at the well of Los Azufres. Emphasizing that the first corresponds to sandy formation system and the other one is in volcanic formation.

## Nomenclature

Capital letters

$M$ Factor incorporated in the inflow relationships

$Q$ Volumetric flow rate

$W$ Mass flow rate

Lower case letters

$p$ Pressure

$q$ Flow rate

$r$ Radius

$s$ Damage effect

Subindex

$D$ Dimensionless value

$e$ Referred to reservoir conditions

max Maximum conditions

o Referred to oil

$s$ Referred to separator conditions

$w$ Referred to well

$wf$ Referred to flowing conditions

$wh$ Referred to wellhead conditions

Greek symbols

$\Delta$ Gradient

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