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Practical Application of the Damage Determination in a Well

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ABSTRACT

The damage effect in a well, as the natural or induced alteration of the petrophysical properties of the rock formation, related with the flow of fluids is discussed.

The damage effect is analyzed, from the decrease in the capabilities of production and/or injection of wells. In the past, the damage effect, ordinarily only was determined through the analysis of transient pressure tests. A methodology, recently introduced is presented here, in order to determine the damage effect using data of output tests. In the practice this methodology uses the geothermal inflow type-curve affected with damage. The determination of the damage value in a well is applicable for establishing its conditions to date of the production test is carried out. At the present the inflow type curve was developed to wells producing flow mixture with \( \text{H}_2\text{O}-\text{CO}_2\text{-NaCl} \).

We propose the methodology to determine the damage in a well and examples of its application using a data set of a well are shown. We used data of three output tests carried out in a geothermal well at different stages of its operative life and the results of the corresponding analysis are shown. The obtained results indicate that the numerical value of the damage effect in the well increases as function of its exploitation time. We discuss the practical application of the knowledge of the damage effect in a well in order to apply operations of remediation in it.

Introduction

Different variables such as, pressure, temperature, viscosity, density, scale formation, among others, affect well productivity performance, but certain actions may favorably change its impact (Lyons and Zaba, 1996). The actions that could change favorably the behavior of the well are the treatments, cleaning, hydraulic fracturing and/or stimulation jobs. Of particular interest to the different actions focused to enhance the productivity, are the permeability and the skin effect. Both of these variables can be obtained from pressure transient tests and should be tested before and after any treatment. The objective of such tests is focused to take reference values that indicate the grade of the enhancement caused by the treatment.

The results of the alterations caused to the formation during the drilling stage, have influence during the well production evaluations. The productivity evaluation of the well is useful in its characterization, and to establish its exploitation designs in order to incorporate it, to the exploitation systems. Evinger and Muskat (1942), Horner (1951) found abnormal drawdown in the pressure, higher to those expected by the variations in the produced flow. The practical result is manifested as the deterioration in the characteristics of the well production, so, the authors found appropriate to introduce the concept of the damage.

The diminution in the productivity is related to the reduction in permeability, which is caused by blockage in the wellbore interface. Such obstruction is originated by the stagnation of the mud slurry on the walls of the well, which sometimes also penetrates the pores in the formation. The mud slurry on the walls of the hole is a thin film similar to the skin, by these reason, the authors used the term “skin,” to relate the damage effect, and the letter “s” for refer to this.

Through the use of the equations for the analysis of the reservoir behavior, can be determined the value of the damage effect, which, could be positive, zero or negative. The value zero of the damage effect indicates the normal state in the well conditions, a positive value of the damage refers to the presence of deterioration conditions in the well and a negative value of the damage indicates an enhancement in the characteristics of the well.

The determination of the damage effect has practical application in determining the state of the well after a treatment, by comparing the value of the damage effect before and after this job.

Skin Effect Related with Productivity Index

The well productivity is characterized by its productivity index \( (J) \) and according with Darcy Law (Maggiolo, 2008) for flow of
fluids through porous media, it is proportional to the flow and inversely to pressure drawdown, whose expression is:

\[ J = \frac{Q}{p_w - p_{wf}} = \frac{Q}{\Delta p} \]  

(1)

where \( Q \) is the mass flow rate, \( p_w \) is the reservoir pressure, \( p_{wf} \) is the bottom-hole flowing pressure and \( \Delta p \) is the difference between \( p_w \) and \( p_{wf} \).

The expression for flow \( (Q) \) in petroleum systems, from Darcy’s Law (Maggiolo, 2008) is:

\[ Q = \frac{0.00708 \text{ Kh} (\Delta p)}{\mu B \left[ \ln \frac{r_w}{r_e} + s \right]} \]  

(2)

where \( K \) is the formation permeability, \( h \) is the formation thickness, \( \mu \) is the fluid viscosity, \( B \) is the fluid formation factor, \( r_e \) is the drainage radius, \( r_w \) is the well radius and \( s \) is the skin effect.

Combining Eq. (1) with Eq. (2) for determining the productivity index, we obtain next expression:

\[ J = \frac{0.00708}{\ln \frac{r_w}{r_e} + s} \left[ \frac{K}{\mu B} \right] \]  

(3)

The different methods proposed to analyze the behavior of the reservoir, initially were focused to transient pressure tests. These methods included, besides the calculation of the permeability, porosity, drainage radius of the reservoir, etc., the determination of the damage effect (Horner, 1951; Matthews et al., 1954; Matthews and Russell, 1967; Earlougher, 1977; Craft et al., 1990; O’Sullivan et al., 2005). The ordinary equation for determining the damage effect in petroleum systems is of the form:

\[ s = 1.151 \left( \frac{\Delta p}{m} - \log t - \log \frac{K}{\phi \mu c r_e} + 3.23 \right) \]

(4)

where \( m \) is the slope of the graph of the time in logarithmic scale against \( p_{wf} \), \( t \) is the period time of the test, \( K \) is the formation permeability, \( \phi \) is the porosity. The other variables were defined previously.

The output tests are used for determining the productive characteristics of the well and to establish the parameters for its exploitation. The graph of each mass flow rate against its corresponding wellhead pressure, is known as the production characteristic curve (or output curve) of the well. This curve is single and identifies the performance of the well for each stage of its operative life.

Gilbert (1954) developed the methodology to characterize the well through the use of its measured data during the output tests. Weller (1966) incorporated calculations of simulations of the flow in the wells and Vogel (1968) proposed the inflow performance relationships using dimensionless variables \((p_D \text{ and } Q_D)\), whose expressions are:

\[ p_D = \frac{p_{wf}}{p_e} \]  

(5)

\[ Q_D = \frac{Q}{(Q_o)_{\text{max}}} \]  

(6)

where \( p_D \) is the dimensionless pressure, \( p_{wf} \) is the bottom-hole flowing pressure, \( p_e \) is the reservoir pressure, \( Q_o \) is the dimensionless volumetric flow rate, \( Q \) is the volumetric flow rate and \((Q_o)_{\text{max}}\) is the maximum volumetric flow rate at the time that the test is done. Vogel (1968) used these dimensionless variables and proposed the inflow performance relationship, whose expression is:

\[ Q_D = 1.0 - 0.2(P_D) - 0.8(P_D)^2 \]

(7)

Different authors proposed their own inflow relationships (Standing, 1970; Fetkovich, 1973; Klins and Majcher, 1992; Klins and Clark, 1993; Wiggins, 1994 among others). However the majority of the proposed inflow relationships maintain the original form of that of Vogel. Klins and Majcher (1992) incorporated the variable they called as \( M \), which influences in the performance of the inflow relationship and is related with the damage effect. According with the characteristics of petroleum systems, the expression is:

\[ M = \frac{\ln \frac{r_w}{r_e} - 0.492}{\ln \frac{r_w}{r_e} - 0.492 + s} \]

(8)

In the development of the geothermal technology, James (1968; 1980; 1989), Goyal et al. (1980), Garg and Kassoy (1981), Grant et al. (1982), among others, used the output curves as useful tools for characterize the geothermal wells. Iglesias and Moya (1990) proposed the dimensionless inflow curve for geothermal systems, considering the fluid composed by pure water. The corresponding expression is:

\[ W_D = 1 - 0.6(p_D)^2 - 0.4(p_D)^4 \]

(9)

where \( W_D \) is the dimensionless mass flow rate, resulting from the ratio of the mass flow \((W)\) and the maximum mass flow rate \((W_{\text{max}})\) of the well. Moya (1994) proposed an inflow relationship considering the fluid as a binary system composed by \( H_2O-CO_2 \) and Meza (2005) considered a ternary mixture \( H_2O-CO_2-NaCl \) whose expression is:

\[ W_D = 1.0 - 0.4399 \left( p_D \right) + 1.1658 \left( p_D \right)^2 - 4.0372 \left( p_D \right)^3 + 3.6697 \left( p_D \right)^4 - 1.3782 \left( p_D \right)^5 \]

(10)

Figure 1 shows a comparative graphic of the Vogel (1968), Klins and Majcher (2002) and Meza (2005) inflow performance relationships. The two first, above mentioned are applicable to petroleum systems and the other is for geothermal systems. In this figure is used the dimensionless mass flow rate \((W_D)\) and dimensionless pressure \((p_D)\).

In order to introduce the damage effect in the geothermal inflow relationships, Aragón (2006), Aragón et al. (2008) proposed an equation for the \( M \) factor, assuming the characteristics of the geothermal systems. The resulting expression is:

\[ M = \frac{\ln \frac{r_w}{r_e} - 0.6603}{\ln \frac{r_w}{r_e} - 0.6603 + s} \]

(11)

The radii of the wells \((r_w)\), of the geothermal systems, vary between 2 and 3.5 inches and generally are used in the majority
of the fields. However, there is some uncertainty to define the appropriate value of the drainage radius of the reservoir ($r_e$). A sensibility analysis about the behavior of the $M$ factor, respect to variation of $r_e$ value is shown in Figure 2.

Geothermal Inflow Performance Relationships Affected with Damage

The combination of the Equations (10) and (11) gives as result the geothermal inflow performance relationships affected with damage, whose expression is:

$$W_D = M \left( 1.0 - 0.4399(p_D) + 1.1658(p_D)^2 - 4.0372(p_D)^3 + 3.6697(p_D)^4 - 1.3782(p_D)^5 \right)$$

(12)

The graphical result of the equation (12) using the factor $M$, for different values of the damage ($s$), is a set of curves, each one representing its respective damage value. The graph is shown in Figure 3, is called as the “geothermal inflow type-curve with damage” whose applicability is focused for determining the damage in a well using data of its output tests.

The measured data during an output test ordinary are taken at well-head conditions, however to use the geothermal inflow type-curve it is necessary transform them, to bottom-hole conditions. In order to transform the measured data, at bottom-hole conditions, we used the WELLSIM program (PBPower, 2005). The maximum mass flow rate for each output test was determined by using the program SISTCURV (Moya et al., 2003), program developed for the analysis of the output tests using inflow performance relationships.

The Equations (5) and (6) were used for determining the respective values of $W_D$ and $p_D$, in order to overlay them into the geothermal inflow type-curve affected with damage. The graph of each one of the set values ($W_D, p_D$) into the geothermal inflow type-curve, is used to identify the curve of damage that best fits to them.
Application of the Geothermal Inflow Type-Curve with Damage Effect to Field Case

In order to demonstrate the applicability about the use of the proposed type-curve, were used data of the well A-13 (Hiriart and Gutiérrez-Negrín, 1997) located in Los Azufres, México geothermal field. Three output test carried out in this well are analyzed:

a) The first output test in this well was carried out at its initial conditions; b) The second one after 4 years of its exploitation and; c) The last with 16 years of exploitation. Figure 4 shows the output curves of the three tests developed in the well, using the measured data taken at well-head conditions.

The value of $W_{\text{max}}$ was calculated and the data were transformed to the bottom-hole conditions. The set of values of $W_D$, $p_D$ for each measurement were obtained and overlapped on the geothermal inflow type-curve. The damage corresponding at the time of each output tests was determined through the identification of the curve that best fits with the data, for each case.

Figure 5 shows the full graph containing the type-curve and the calculated dimensionless values using the measurements of the three tests in the well. From the analysis of this figure, it can be seen that the damage value using the proposed methodology is of $s = -2.1$ at start-up conditions. After 4 years of exploitation, the damage effect was determined in a value of $s = -2$ and with 16 years of exploitation the damage effect was calculated in $s = 0.5$. So, the first observation resulting from last figure is the increase of the damage effect along the exploitation time of the well.

Discussion

The decline in the productivity of the well by effect of its exploitation time is shown in Figure 4. Along the first 4 years of exploitation in the well, the decline can be considered small with a drawdown of about 6%. But between the year 4 and the year 16, the productivity decreases in about 26% of its original condition. The results of the methodology used maintain a consistent behavior in relation with the period time of operation of the well. The negative value of the damage effect obtained at the start-up conditions in the well is due to the cleaning operations done during its completion stage. So, for initial conditions it can be assumed that the well maintains characteristics of improvement.

From the analysis made, the determined values of the damage effect increase in direct function with the exploitation time of the well. However, those parameters (damage effect and exploitation time) are inverse function of the well productivity. Thus, the identification of the presence and its increase of the damage effect in the well is the signal that indicates the appropriate time to take decisions about the best treatment to apply in order to improve its productivity.

Conclusions

The practical application of the determination of the damage effect in a well is shown, in order to take decisions about the operations of remediation to apply in it.

A review about the development of the technology to characterize the productivity of the wells, using inflow performance relationships is shown.

The development of the inflow performance relationships, applied to petroleum and geothermal systems is discussed. The coupling of the M factor into the inflow relationships, to determine the damage effect is described.

The geothermal inflow type-curve affected with damage and the methodology to determine the damage in a well, are proposed. The applicability of the methodology using the type-curve...
proposed is shown, using data of three output tests of a well of a Mexican geothermal field.

From the analysis was determined that the numerical value of the damage effect increases with the exploitation time, and the relation with deterioration of the productive characteristics of the well is shown. The knowledge of the damage effect is useful to take decisions about the best remediation treatment to apply in the well to improve its productivity.

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References


