

A Descriptive Analysis of Damage Effect Obtained from Transient Pressure Tests and the Damage Determined Using Inflow Curves

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ABSTRACT

The damage effect in a well is defined as the natural or induced alteration of the petrophysical properties of the rock formation, which characterizes the flow of fluids.

The natural result of the damage existence is the decrease of the formation permeability, the increase in the drawdown pressures of the system and the diminution of the flow rate capacity. Due to decrease of the capabilities of the production and injection wells, the concept of the damage effect is analyzed.

The damage effect, ordinary is determined through the analysis of transient pressure test. A new methodology was introduced recently and is presented here, in order to determine the damage effect using data of output tests. This methodology uses the geothermal inflow type-curve affected with damage, which is a useful tool for determining the value of the damage in a well at the time of its output test. At the present the inflow type curve is applicable to wells producing flow mixture with H_2O-CO_2-NaCl .

In this paper we propose the methodology to determining the damage in a well and an example of its use with data set of a well is shown. The obtained results indicate that the numerical value of the damage in the well increases as function of its exploitation time.

1. INTRODUCTION

The steady state of the formation is perturbed from the same time at the drilling operations start. The drilling jobs produce alterations to walls of the hole. The drilling mud produce changes in the permeability formation through the suspended clays, the mud slurries and its chemical composition. Also the cement slurries are housed in the pore formation, during the cementation stages of the casings, and modify its original conditions. Even the wells are cleaned during its completion stage, but sometimes it is not possible to restore its original conditions.

The results of all alterations caused to the formation during the drilling stage, are present at the time of 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 production systems. Evinger and Muskat (1942), Horner (1951) found abnormal drawdown pressures, higher to those expected by the variations in the discharged flow. Due that this practical result is related to the deteriorative in the characteristics of the well production, 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 could penetrate 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 called as "skin" for to relate the damage effect, using the letter "s" for refer to it.

The knowledge about the presence, and the value of the damage effect in a well, is useful in taking decisions over the planning of its operations, such as cleaning, repairs, stimulations, among others treatments. The scope of these operations is the enhancement of the productive characteristics of the well.

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.

2. THEORETICAL CONCEPTS OF THE DAMAGE EFFECT

Initially, the proposed methods to analyze the behavior of the reservoir, 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 normal equation for determining the damage effect is of the form:

$$s = 1.151 \left(\frac{P_{wf} - P_i}{m} - \log t - \log \frac{K}{\phi \mu c_i r_w^2} + 3.23 \right) \quad (1)$$

where s is the damage effect, p_{wf} is the bottom-hole flowing pressure, p_i is the initial pressure, 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, ϕ is the porosity, μ is the viscosity of the fluid, r_w is the radius of the well.

The output tests are another useful technical tool to characterize the wells, and to analyze the behavior of the reservoir. These tests are used for determining the productive characteristics of the well and to establish the parameters for its exploitation. The methodology to develop an output test, consists in to open the well at different mass flow rates taking a care of maintain an orderly sequence. For each mass flow rate it must measure the corresponding wellhead pressure. The graph of each mass flow rate versus its corresponding wellhead pressure is known as the production characteristic curve (or output

curve) of the well. This curve 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 and Q_D), whose expressions are:

$$P_D = \frac{P_{wf}}{P_e} \quad (2)$$

$$Q_D = \frac{Q_o}{(Q_o)_{max}} \quad (3)$$

where P_D is the dimensionless pressure, P_{wf} is the bottom-hole flowing pressure, P_e , is the reservoir pressure, Q_D is the dimensionless mass flow rate, Q_o is the mass flow rate and $(Q_o)_{max}$ is the maximum mass 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:

$$Q_D = 1.0 - 0.2(P_D) - 0.8(P_D)^2 \quad (4)$$

Different authors proposed their respective 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 several variables influencing in the performance of the inflow relationship and are related with the damage effect. According with the characteristics of petroleum systems, the expression is:

$$M = \left(\frac{\ln \frac{r_e}{r_w} - 0.492}{\ln \frac{r_e}{r_w} - 0.492 + s} \right) \quad (5)$$

where M is a multiplier factor that is introduced in the inflow relationships.

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:

$$W_D = 1 - 0.6(P_D)^2 - 0.4(P_D)^4 \quad (6)$$

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_{max}) of the well. Moya (1994) proposed an inflow relationship considering the fluid as a binary system composed by H_2O-CO_2 and Montoya considered a ternary mixture H_2O-CO_2-NaCl . The expression of this last assumption is:

$$W_D = 1.0 - 0.4399 (P_D) + 1.1658 (P_D)^2 - 4.0372(P_D)^3 + 3.6697(P_D)^4 - 1.3782(P_D)^5 \quad (7)$$

Figure 1 shows a comparative graphic of the Vogel (1968), Klins and Majcher (1992) and Montoya (2003) inflow performance relationships. The two first, above mentioned are applicable to petroleum systems and the other is for geothermal systems. Aragón (2006), Aragón et al. (2008) proposed an equation for the M factor, considering the characteristics of the geothermal systems. The resulting expression is:

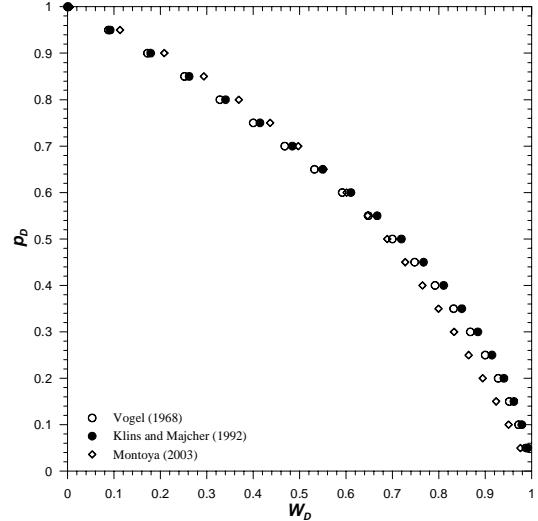


Figure 1: Comparison of two of the petroleum inflow performance relationships (Vogel, 1968; Klins and Majcher 1992) with the geothermal inflow performance relationship for a ternary mixture (H_2O-CO_2-NaCl).

$$M = \left(\frac{\ln \frac{r_e}{r_w} - 0.6603}{\ln \frac{r_e}{r_w} - 0.6603 + s} \right) \quad (8)$$

The radii of the wells (r_w), for geothermal systems, vary between 2 and 3.5 inches and could be considered constants for the majority of the fields. However, there is some uncertainty respect to appropriate value of the drainage radius of the reservoir (r_e). By this reason in Figure 2 is shown a sensibility analysis about the behavior of the M factor, respect to variation of r_e value. Table 1 shows the respective values calculated of the M factor, varying the r_e values.

Table 1: Variation of the M factor as function of value of r_e .

s	Factor M			
	$r_e = 100$ m	$r_e = 120$ m	$r_e = 140$ m	$r_e = 150$ m
-5	3.468	3.265	3.117	3.057
-4	2.322	2.247	2.189	2.165
-3	1.745	1.713	1.687	1.677
-2	1.397	1.384	1.373	1.368
-1	1.165	1.161	1.157	1.155
0	1	1	1	1
1	0.875	0.878	0.880	0.881
2	0.778	0.782	0.786	0.787
3	0.700	0.706	0.710	0.712
4	0.637	0.643	0.647	0.650
5	0.584	0.590	0.595	0.597

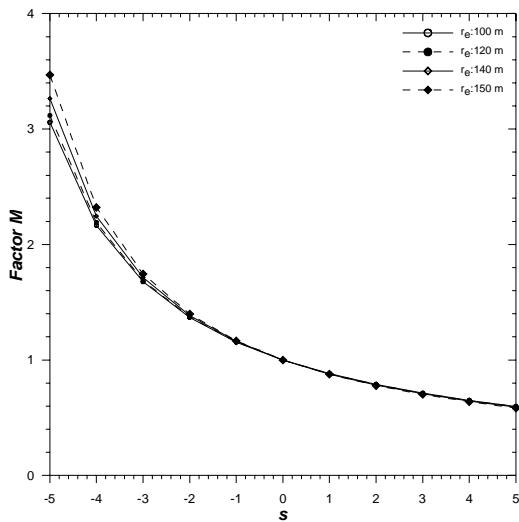


Figure 2: Variation in the behavior of the factor M, with respect to the damage value, using different values of the drainage radius of the reservoir.

3. GEOTHERMAL INFLOW PERFORMANCE RELATIONSHIP Affected WITH DAMAGE

The combination of the equations (7) and (8) gives as result the geothermal inflow performance relationships affected with damage, whose expression is:

$$W_D = M \left\{ \begin{array}{l} 1.0 - 0.4399(P_D) + 1.1658(P_D)^2 \\ - 4.0372(P_D)^3 + 3.6697(P_D)^4 \\ - 1.3782(P_D)^5 \end{array} \right\} \quad (9)$$

The graphical result of the equation (9) using different values of the factor M, according with the variation of the damage (s) value is a set of curves, each one representing its respective damage value. The graph referenced, is shown in Figure 3 and is called as the "geothermal inflow type curve with damage" and is useful for determining the damage in a well using data of its output tests. This type-curve was developed, assuming conditions of the reservoir, composed by a ternary mixture of H_2O - CO_2 - $NaCl$.

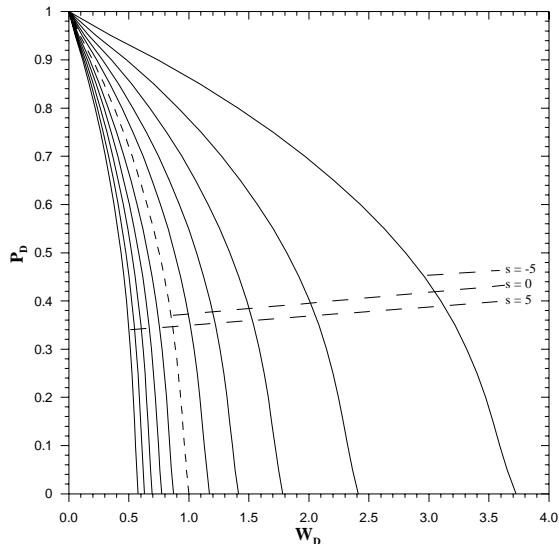


Figure 3: Geothermal inflow type-curve for determine the damage in wells, using data of their output tests.

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

The equations (2) and (3) 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. So, by this way it is possible to determine the value of the damage existing in the well, at the stage life of the well that the output test is carried out.

4. 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 Az-13 (Hiriart and Gutiérrez-Negrín, 1998) located in Los Azufres, México geothermal field. Three output test carried out in this well, are analyzed and its results shown in this paper. The first output test carried out in this well was at its initial conditions, the second after 4 years of its exploitation and the last with 16 years of exploitation.

Figure 4 shows the output curves of the three tests developed in this well, using the measured data taken at well-head conditions. The W_{max} values were calculated and the data were transformed to the bottom-hole conditions using the programs (WELLSIM and SISTCURV) above mentioned.

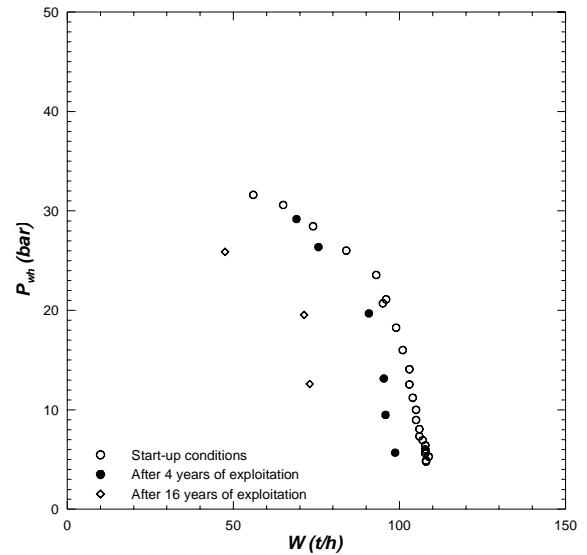


Figure 4: Output curves of well A-13, at start-up conditions and after 4 and 16 year of exploitation.

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 by identifying the curve that best fits with the data, for each case. Figure 5 shows the full graph

containing the type-curve and the dimensionless values of the well, calculated from the measurements.

From figure 5 it can be seen that the damage value using the proposed methodology is of -2.1 units at start-up conditions. After 4 years of exploitation, the damage was determined in a value of 0.5 units and with 16 years of exploitation the damage was calculated in 0.5 units. So, according with the above mentioned it is observed that the damage effect, increases with the exploitation time.

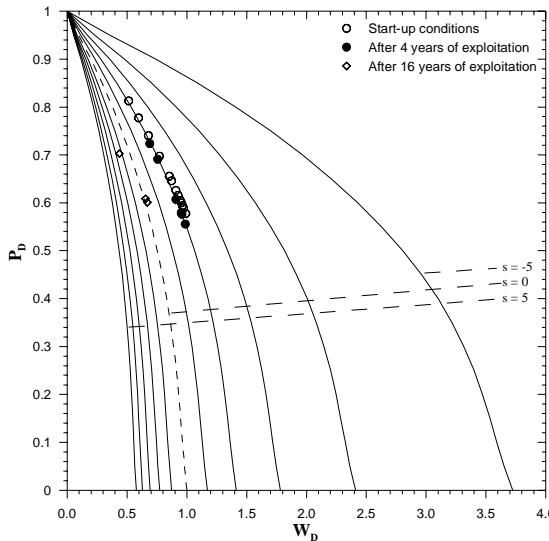


Figure 5: Application of the geothermal inflow type-curve for determining the damage value in well A-13 at different stages of its operative life.

5. DISCUSSION

It is appropriate to make mention that the behavior of the M factor as function of the variation of the damage value (s) in equation (8), shows a small variations for different values of the drainage radii (r_e). From the analysis of the Figure 2 and Table 1 it can be seen that the values of the M factor did not vary for the different values of r_e used. Then, the use of equation (8) into the inflow relationship for the damage calculation could be considered acceptable.

The results of the methodology used maintain consistent behavior with the period time of operation of the well. The negative value of the damage effect obtained for the start-up conditions in the well is related with the cleaning operations made during its completion stage. So, for initial conditions could be considered that the well maintains characteristics of improvement. The behavior of the output curves shown in Figure 4, indicates that the well presents a decrease in its productive characteristics with production time.

From the analysis that has been done, 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 in inverse function with the well productivity.

6. CONCLUSIONS

A review about the development of the technology to characterize the productivity of the wells is shown. The methodology uses the inflow performance relationships.

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.

It is analyzed the behavior of the M factor, which incorporates the damage effect in the inflow relationships, emphasizing that the variations in the geometry of the reservoir, does not substantially modify the inflow relationship.

The geothermal inflow type-curve affected with damage is shown. This type-curve is useful for determining the value of the damage effect, using data measured during the output tests of the wells, whose production is a mixture of two phase flow.

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

The numerical value of the damage determined in the analyzed well, increases with the exploitation time, it is related with the deterioration of the productive characteristics of the well.

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