Diagnostic of results of hydro-dynamical studies of reservoirs

E E Levitina

Tyumen Industrial University, 38, Volodarskogo street, Tyumen, 625000, Russian Federation

E-mail: 934964@mail.ru

Abstract. At present, the technique of interpreting the pressure diagrams obtained in the wells logging achieved such a high level that in many qualitatively conducted hydro-dynamical studies, it is possible, in addition to the basic parameters of the reservoir permeability, hydroconductivity, reservoir pressure and skin effect, to determine even the most important characteristics of the drainage area, such as, for example, the filtration properties of a fracture obtained during reservoir hydraulic fracturing, the presence and characteristics of the pore-fracture environment composing the reservoir, performance feature of layers and interlayers, types of reservoir heterogeneity and others.

1. Introduction

When interpreting the results of hydro-dynamical studies, the appropriate reservoir models are usually selected on the basis of observing the nature of the curvature of individual sections of the pressure recovery curve, built on a graph with semilog coordinates – $P – \lg t$. For example, it is known that if the work schedule obtained in this way has a curvature with slopes of two fixed sections, the final and the initial ones, in a 2: 1 ratio, then a sharp impermeable boundary (discharge, barrier, etc.) must be included in the model of the reservoir in question. If the graph of the pressure recovery curve consists of two parallel sections, this indicates the logging of a well with a complex profile (deviant directional) or a possible pore-fracture reservoir structure. In order to attribute the study results to one or another kind (structure) of the reservoir, it is not enough to consider only the type of the obtained pressure recovery curve. It is also necessary to consider the results of inclinometry and those of geophysical studies, on which basis the profile of the borehole and the structure of the studied reservoir – stratification, heterogeneity and interlayer connectivity with each other, are clarified.

2. Results and Discussion

In the 80s of the last century, there was a revolutionary change in the methodology for applying various methods of analyzing and interpreting the pressure diagrams. It was first proposed to use bilogarithmic graphs as diagnostic of the resulting pressure diagrams. A unique opportunity was found when constructing the pressure curves and the pressure derivative curves on the same graph. It was possible to directly visualize the features of the filtration processes at different test stages. It was proposed to build working diagnostic charts in the coordinates:

$$\lg P – \lg t \text{ and } \lg P’ – \lg t,$$

(1)
\[ P' = \frac{\partial \Delta P}{\partial (\ln \Delta t)} \]  

or

\[ (\Delta P)' = (P - P_0)' = \frac{\partial \Delta P}{\partial (\ln t)}. \]  

In this way, \( P' \) - the rate of the pressure change with respect to the time logarithm, and, therefore, is equal to the slope of the curve \( P(t) \) on a semi-log plot. The main idea of the derivative is to calculate the slope at each point of the pressure curve on a semilog graph and plot the points on the graph in bilogarithmic coordinates.

In the dimensionless form, the pressure change has the form:

\[ P_D = \frac{1}{2} \left[ \ln t_D + 0.81 + 2S \right]. \]  

If \( + \ln C_D \) and \( - \ln C_D \) will be added in the expression \( \left( \ln t_D + 0.81 + 2S \right) \), then we get as the result:

\[ P_D' = \frac{1}{2} \left[ \ln \frac{t_D}{C_D} + 0.81 + \ln C_D \exp(2S) \right]. \]  

Then the logarithmic derivative of the pressure for the radial inflow is:

\[ P_D' = \frac{\partial P_D}{\partial \left( \ln \frac{t_D}{C_D} \right)} = 0.5. \]  

Therefore, the sections of the derivative curves related to the radial inflow are horizontal straight lines with an ordinate equal to 0.5 (in dimensionless coordinates).

When analyzing the data, the hydro-dynamical pressures and pressure derivatives are plotted on a logarithmic scale. The axe scales of the actual pressure diagrams are chosen to be the same as the scale of the reference curves.

Let us consider an example of plotting the derivative of the pressure when calculating reservoir parameters for the pressure recovery curve obtained in a well with a crack. The pressure recovery curve has an initial section characterizing the linear flow and the final section characterizing the radial flow. But for the exact determination of the final section, it is necessary to construct the corresponding derivative in logarithmic coordinates. Figure 1 shows the pressure recovery curve for a well with a crack length of 10 meters. It was found out that for short cracks an initial rectilinear section is clearly manifested, both on the pressure curve and on the derivative, which characterizes the linear flow near the crack area. And also the classical final section formed, characterizing the radial flow. The derivative graph clearly goes to the horizontal, which proves the formation of the radial flow.
Figure 1. Pressure recovery curve and its derivative for a crack length of 10 meters $R_0 = 250$ m

Many other situations exist and are being developed (layering, porous-fractured reservoir, etc.), recognized using similar diagnostic charts to assess the quality of information about the reservoir properties.

At the same time, it is required to diagnose the quality of the initial information in the obtained pressure recovery curves, complex parameters etc., which can be distorted for technical reasons. The first question in choosing a particular design scheme for interpreting the results of the study should be whether the detected anomalies in the pressure recovery curve are associated with any well effects (equipment operation, packers, wellhead switching of valves, etc.) or it is the reaction of the reservoir to transitional processes of pressure change occurring after the shut-down of a flowing well.

Here is an example of the diagnostic of the pressure curve recorded in well 113 of the Ust-Tegusskaya area in the interval of 2481 – 2488 m. Figure 2 shows the pressure diagram recorded during the well logging using a jet pump and overlapping the bottom hole with a packer.

Figure 2. Hydro-dynamical studies at well 113 of the Ust-Tegusskoye field

The reservoir was first subjected to intensification by the method of impulse action. Then a series of short-term performances with the recording of the pressure recovery curve was made (duration of each period was one or two hours). After the 6th last two hour performance, the well was stopped for 16 hours to record the pressure recovery curve (Figure 3). After recording the pressure recovery curve,
several more cycles of short (up to two hours) performances of the well with the recording of the initial sections of the pressure recovery curve were carried out.

**Figure 3.** Horner’s pressure recovery curve

The pressure recovery curve, reconstructed according to Horner's method, has an explicit final rectilinear plot – 1 (Figure 3). The "zigzag" is also found in the final part of the curve – 2. When interpreting the resulting diagram, the reservoir parameters were calculated for each curve section. The indicator curve for this well is shown in Figure 4.

**Figure 4.** Indicator diagram, Ust-Tegusskaya well 113

Determination of the reservoir hydro conductivity along the 1st section of the pressure recovery curve is equal to \( kh/\mu = 4.21 \ \mu m^2 \cdot cm/(mPa \cdot s) \), and along the 2nd sections of the pressure, the recovery curve is equal to \( kh/\mu = 0.39 \ \mu m^2 \cdot cm/(mPa \cdot s) \), i.e., ten times less. If the hydraulic conductivity of the reservoir is calculated from the inductive electro-magnetic logging, we obtain \( kh/\mu = 2.45 \ \mu m^2 \cdot cm/(mPa \cdot s) \). As it is known, along the indicator curve, the average parameters between the bottomhole formation and the remote formation zone are determined, and the parameters of the remote zone are determined from the pressure recovery curve. Therefore, the value of the hydraulic conductivity determined by the pressure recovery curve cannot be less than that determined by the inductive electro-magnetic logging. Therefore, we can conclude that the most final "zigzag" of the pressure recovery curve is a non-informative part of the pressure curve.

Skin-effect also differs significantly when choosing one or another section of the pressure recovery curve for calculating the reservoir parameters: along the 1st section, it is 3.93; and along the 2nd one it is minus 3.39. That is, in the first case, the reservoir has a significant pollution and it is necessary to
provide for its intensification and productivity increase of 2-3 times. In the second case it was found out that the reservoir is not contaminated and also has an increased permeability of the bottom hole formation zone. At the same time, no special measures were taken to activate the reservoir at the time of the study, except for the pulsed impact on the bottom hole formation zone by the jet pump during the reservoir study. Consequently, if there were no impacts on the reservoir, the negative value of the skin effect should be attributed to the fact that either the pressure recovery curve was not recovered or the working section of the pressure recovery curve for calculating the reservoir parameters was incorrectly selected.

3. Conclusion

Thus, we can draw the following conclusions on the diagnostic of the results of the hydro-dynamical studies interpretation and determination of the information content of the pressure recovery curve:

1. Since the pressure recovery curve more accurately reflects the filtration properties of the reservoir than the inductive electro-magnetic logging, the hydraulic conductivity calculated from the pressure recovery curve (when obtaining the final section) should be higher than the hydraulic conductivity, determined by the inductive electro-magnetic logging. Consequently, the most finite “zigzag” on the pressure recovery curve is the non-informative part of the pressure curve.

2. Negative skin effect is the evidence of increased permeability in the bottom hole formation zone. If there were no impacts on the reservoir, the negative value of the skin effect should be attributed to the fact that either the pressure recovery curve was not recovered or the working section of the pressure recovery curve for calculation of the reservoir features was incorrectly selected.

3. The sharp fractures of the pressure recovery curve, especially at the last recording stage, are evidence of the influence of some side factors (leakage of equipment, unplanned inclusion of wellhead valves, etc.).

4. When plotting the pressure derivative graphs in bilogarithmic coordinates, diagnostic curves allow evaluation of the quality of informative features of the reservoir properties along different sections of the pressure recovery curve.

References

[1] Karnaukhov M L, Sidorov A G 2003 Diagnostic of Pressure Curves Obtained During the Wells Logging and Determination of the Possibility of Reservoir Features Using Various Filtration Models Proc. of the Int. Scientific and Technical Conf. on the 40th anniversary of Tyumen State Oil and Gas University “Problems of development of fuel and energy complex in Western Siberia at the present stage” (Tyumen Izd-vo Slovo) pp. 198-201

[2] Evstrakhina E E Soloviev O I and Rozhkov I V 2008 Diagnostic of Results of Hydro-Dynamical Studies and Determination of the Information Content of Pressure Recovery Curve New technologies for the fuel and energy complex of Western Siberia 3 377-383

[3] Levitina E E Pyankova E M and Lesnoi A N 2010 Determination of Reservoir Properties on the Basis of Analysis of Pressure Measurements by Deep Sensors Automatizatsiya, telemehanizatsiya, isvyaz v neftyanoipromyshlennosti 3 29-33

[4] Levitin R E Zemenkov Y D 2016 Fuel Temperature Fluctuations During Storage IOP Conf. Series: Materials Science and Engineering 154 012001

[5] Levitin R E Tryascin R A 2016 Determining Fuel Losses in Storage Tanks Based on Factual Saturation Pressures IOP Conf. Series: Materials Science and Engineering 154 012022

[6] Sarancha A V Shuldikova N S 2017 Results of Research and Commercial Production of Shale Oil in Bazhenov Formation on Ai-Pimskoe Field IOP Conf. Series: Earth and Environmental Science 87 042018