Optimization of transient well test technology for low permeability complex reservoir

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Abstract. This paper summarizes the experience of conducting hydrodynamic studies on transient filtration modes (pressure build up method) using an example of a low-permeable formation with a complex structure. Such objects are distinguished by a high degree of differentiation of reservoirs by filtration-capacitive properties, which affects the design of ongoing research. The relevance of the work is due to the need to justify the optimal research time for reservoirs with the considered properties in terms of obtaining high-precision data and minimizing oil production losses. In order to fulfill these tasks, it is urgent to develop a design for hydrodynamic research of wells. Research modeling was performed using the Kappa Saphir software product. The design will provide an integrated approach to modeling the process of conducting research and forecasting the data obtained. The design will optimize research time. Based on the calculation results, the duration of the effect of the wellbore effect and the time of the beginning of the boundary effect were analyzed. The reasons for the long exit to the pseudoradial flow regime were considered. In order to optimize the research process, an analysis of the error in determining the pressure was made, depending on the duration of the study. Taking into account the error, the optimal time for registering the PBU is proposed.

1. Introduction

The structure of oil reserves in Russia currently has its own special characteristics. Many large oilfields are at the final stage of development, and the reserves of input fields are in most cases classified as hard to recover [1].

Most of the hard-to-recover reserves are localized within the fields, which according to the complexity of the geological structure belong to the categories of “complex” and “very complex” [2]. Productive formations are characterized by significant macroinhomogeneity of reservoir properties along the height and strike. With a high degree of heterogeneity, the most permeable interlayers are primarily involved in production. This may be the reason for their outrunning watering with significant current reserves, which remain localized in low-permeability zones. To extract hydrocarbons under such conditions, technologies, such as horizontal well drilling, hydraulic fracturing, chemical methods to increase waterflooding efficiency are actively applied. Currently, there is a further development and improvement of production methods and oil recovery enhancement methods, which makes it possible to obtain industrial influx from reservoirs, the development of which was previously considered economically inexpedient.

Hydrocarbon production technologies and methods of stimulating reservoirs in order to increase oil recovery should be scientifically substantiated and well-planned in order to most efficiently develop...
hydrocarbon reserves. To solve the tasks set, complete and reliable information is needed on the structure and properties of productive formations, their current state [3]. The above data can be obtained by conducting well tests.

2. Transient well test method

Well tests are based on measuring pressure and fluid flow in a well. Further determination of the formation parameters is based on the use of the dependence of the pressure change in time or the change in flow rate in time for the transient process after starting, stopping or changing the mode of operation of the well.

In studies under non-stationary conditions, data are obtained using two technologies: PBU technology - pressure build up curves and LBU - level build up curves.

According to the PBU technology, the change in pressure in a stopped well is caused to the maximum extent by processes in the formation: the continued movement of fluid away from the well and its compression in the well and the bottomhole zone. “Clean PBU curve” implies the absence of fluid from the formation into the wellbore of a stopped well [4]. In this case, there is no movement in the skin zone and therefore it does not affect the nature of the pressure change over time.

According to the nature of the pressure change in the PBU curve section, the formation hydraulic conductivity, formation pressure, formation skin factor are determined, and the productivity coefficient is calculated. PBU curve is used to identify boundaries and conditions at the boundaries, the mode of filtration in the reservoir.

In practice, the registration of the PBU is carried out in a stopped well. At the same time, for some time the processes in the wellbore influence the well flow: fluid flow from the formation into the wellbore (the so-called afterflow effect), level rise and compression of the fluid in the wellbore and gas-air mixture in the free volume of the well above the level of the fluid column.

The afterflow effect or the influence of the wellbore distorts the initial section of the PBU curve. The distorted area is then isolated and excluded from processing [5].

The end section of the PBU curve during long-term registration is distorted due to the influence of processes at external borders, due to the influence of neighboring wells. Identification of various types of boundaries and conditions at the borders allows monitoring the reservoir according to well tests.

The PBU curve section, defined as a section of the radial flow in the formation, not subject to the influence of the afterflow effect and the external boundary, is processed by various methods [4, 5].

If the duration of the well operation (T) with a constant flow rate (Q) before stopping the registration of the PBU is more than 2 times the duration (t) of the registration of the PBU, then this curve is processed by the standard MDH method (tangent method). According to the results of processing we can determine the hydraulic conductivity of the formation and skin factor and calculate the potential productivity, expected productivity taking into account the skin factor.

If the duration of the well operation (T) with a constant flow rate (Q) before stopping the registration of the reservoir pressure is less than the duration (t) of the registration of the reservoir pressure (the so-called reservoir after short-term operation of the well with a constant flow rate), then this reservoir flow is processed by the Horner method. According to the results of processing we can determine the hydraulic conductivity of the reservoir and reservoir pressure; using the pressure value at the time the well stops, find the skin factor; calculate the potential productivity, expected productivity taking into account the skin factor.

If the well flow rate to a stop did not remain constant, i.e. well during a time comparable with the time of registration of the reservoir pressure has worked with several constant flow rates (the so-called reservoir pressure after cyclic operation of the well). Then this reservoir is processed according to a special algorithm that takes into account the history of the change in flow rate using the modified Horner method. According to the results of processing we can determine the hydraulic conductivity of the reservoir and reservoir pressure; using the pressure value at the time the well was stopped and the background of the well before shutdown, the skin factor is calculated; potential productivity, expected productivity taking into account the skin factor and the ratio of expected productivity to potential.
For reservoirs of complex structure, the interpretation of research results is a difficult task [6]. This is mainly due to the fact that the radial inflow regime can be distorted by boundary effects. For example, interference with surrounding wells, the presence of geological heterogeneities - zones of facies substitution, impermeable boundaries.

In order to improve the quality of research, the development of research design is proposed [7]. The main goal of design is to predict the duration of work in a certain mode; to identify the most frequently occurring factors and take measures to reduce their negative impact; to evaluate the possibility of obtaining reservoir properties and parameters of the well; to estimate oil production losses.

3. Objects of study
A terrigenous complex reservoir is considered as an object of research. The oil deposit is massive, vaulted. Main features of the object are reservoir compartmentalization, lateral and thickness heterogeneity; the presence of a gas cap and a powerful aquifer; low permeability (average 15 mD). Oil is produced using horizontal wells.

4. Results and Discussion
The design of the hydrodynamic studies was carried out in the Saphir software product of the Ecrin package of KAPPA Engineering. As the initial information for creating the design, the data obtained in the course of geophysical surveys and previous well tests were used.

The parameters of a horizontal well of the formation with a conditionally average time to reach the pseudo-radial flow mode are presented in Table 1.

| Initial reservoir pressure, MPa | Effective thickness, m | Porosity, % | Oil viscosity, cP | Total compressibility, g/sm^3 | Oil density, 1/MPa•10^-4 |
|-------------------------------|-----------------------|-------------|------------------|-----------------------------|--------------------------|
| 28                            | 25                    | 20          | 1.7              | 17                          | 0.855                    |

As a result of numerical simulation, the diagnostic graphics of the PBU were obtained. Figure 1 shows a detailed graph for a well with averaged parameters over the reservoir. According to the performed simulation, afterflow effect ends after 0.041 days, the end of the early radial mode was diagnosed after 0.25 days, the beginning of the pseudo-radial mode - after 250 days.

In order to obtain correct results in the interpretation of the PBU curve, the duration of the radial mode should be at least 1/2 of the logarithmic cycle [8]. Subject to the specified condition the duration of the registration of the PBU will be about 474 days.

As a result of the design, a thorough analysis of the initial data was carried out and numerical simulation of the bottomhole pressure behavior for the well was performed. According to the simulation results, the recommended study duration is of great importance - more than a year.

Even if achieved, the pseudo-radial flow regime will be hidden by the influence of neighboring wells and / or boundaries of constant pressure (gas cap, powerful aquifer) [9]. Even if the well operation history is reached and set before the shutdown (duration is 5 well test cycles), the obtained reservoir pressure value will correspond to the pressure at the beginning of the given history (from six months to several years before the start of PBU). Thus, the obtained value will be irrelevant for the purpose of monitoring field development.
Given the above, the exact value of the reservoir pressure of horizontal wells revealing low permeability reservoirs is very difficult to obtain. You can only get an estimate of the reservoir pressure with a certain error (5 - 7 atm.)

For the conditions of the considered reservoir three wells were selected - with the maximum, average and minimum time to reach the pseudo-radial regime. For them, the errors in determining the reservoir pressure were calculated depending on the duration of the well shut-off for the study. The results are presented in Figure 2.

Thus, creating a design for a particular well, it is also possible to take into account the error in determining the reservoir pressure and select the most optimal time for research to obtain highly informative data, but also take into account minimization of oil production losses [10]. According to the
data obtained, for wells with a conditionally average time to reach the pseudo-radial mode, the shutdown duration within 5-7 days will be minimally sufficient. For wells with a conditionally maximum time to reach the pseudo-radial mode, the study time will be from 20 days.

5. Conclusions
The results of well tests are key information in the planning and control of field development. They allow determining and refining the geological structure, control and monitor the energy state of the formation and field development, determine the current state of the well and the formation, justify and control the effectiveness of geological and technical measures.

At the same time, the main task in the planning of well tests is to evaluate the duration of the study, which provides data recording under the radial filtering mode. However, the time to reach the pseudo-radial flow regime, especially for horizontal wells revealing low-permeability reservoirs, can often reach very large values. Research results with a duration that does not allow recording the radial flow regime are, as a rule, uninformative. In this regard, when planning the duration of the well tests, it is necessary to determine the balance between the cost of the study and the value of the information that it gives.

In this work, we examined transient well test method by recording PBU curve. When planning the duration of each specific study, it is proposed to rely on the results of the study design, to take into account allowable losses in oil production and a possible error in determining reservoir pressure.

A research design has been created for a conventionally medium well that reveals a reservoir of complex structure and low permeability. It is shown that reaching the pseudo-radial filtering mode is achieved after 150 days.

A well shut-in with a duration of 2 days (planned shutdowns of the wells on the oilfield) will not allow obtaining information on reservoir pressure with an allowable error.

For horizontal wells with conditionally average parameters, the recommended duration of the PBU (with an error in determining the reservoir pressure of 5 - 7 atm) is 5-7 days.

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