Adapting the Method of Directional Unloading of the Formation for Low Permeable Deposits

V. I. Karev and S. O. Barkov

Abstract The paper is devoted to considering the possibility and manners of applying the method of directional unloading of the formation (DUF) served for increasing well productivity for low permeable deposits. An analysis of stress state in the vicinity of a well for various geometry of borehole bottom is presented. The methodic of experimental study of deformation and fracture processes near the well for conditions of certain field is developed on the base of this analysis. According this methodic, the tests of specimens cut from reservoir rock under study have been carried out by using the unique setup of IPMech RAS Triaxial Independent Load Test System. The results of experiments allowed the practically important conclusions about the possibility of applying DUF metod for low permeable deposits and the manners of its applicability.

Keywords Low-permeability reservoirs · Directed unloading of formation method · Triaxial independent load test system · Strains · Stresses · Permeability

1 Introduction

The relevance of the work is due to the reduction of the resource base of hydrocarbon raw materials and the need to develop and adapt new efficient environmentally friendly production technologies for the conditions of fields with hard-to-recover reserves, primarily with low-permeability reservoirs [1–3]. These technologies include: multistage hydraulic fracturing [4, 5], wave action [6], the method of directional unloading of the formation (DUF) [7–9]. DUF was developed at the IPMech RAS and passed successful pilot field tests in the fields of Western Siberia and the Urals. The method is based on a geomechanical approach and involves the creation of stresses in the near-wellbore zone, leading to rock cracking and an increase in permeability.

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2 The Problem

The main questions that need to be answered when using the DUF method are what stresses should be created in the formation to cause multiple rock cracking, and what technological operations are necessary for this. The type and level of required stresses depend on the design and deformation properties of the rock, the depth of the formation bedding, reservoir fluid pressure. There are two ways to change the stresses in the vicinity of the well: reduce the pressure in the well and change the bottomhole geometry (remove the casing, make perforations, cut slots). The use of DUF in fields with low-permeability reservoirs, due to the increased strength of the rocks, may require preliminary creating of stress concentrators into the formation—perforation of a certain type and density, including in uncased wells. It is possible to determine the parameters of the method (the magnitude of the pressure drawdown, technological operations for the formation of the required bottomhole geometry) on the basis of laboratory tests that simulate on specimens of reservoir rocks of the field real stresses arising at implementing method. To do this, it is necessary to carry out a theoretical analysis of the stress state in the vicinity of the well for various bottomhole designs, on its basis to develop a laboratory test procedure.

The work carried out the adaptation of the DUF method for the conditions of one of the gas condensate field, which has a low-permeability reservoir and is located in the north of Eastern Siberia. Calculations of stresses acting in the vicinity of perforations in cased and uncased wells have been carried out. On the Triaxial Independent Loading Test System (TILTS) of IPMech RAS [9], a series of tests of rock samples from the reservoir of this field was carried out using special loading programs.

3 Stress State in the Vicinity of a Well for Various Constructions of the Bottom Hole

3.1 Stress State in the Vicinity of a Perforation Hole for a Cased Wellbore

The stress state in the vicinity of a perforation hole for a cased well is determined by the external stress from the rock pressure in the depth of the formation q ($q < 0$, since compressive stresses are considered negative), the back pressure on the formation from the side of the cement stone and the fluid pressure inside the perforation hole for a cased well, equal to the pressure in well p_w. It is generally accepted that on the cased hole contour, after the cement slurry has hardened, the pressure is restored completely to the rock pressure value $|q|$.

Then from the solution of the Lamé problem [10] for the effective stresses acting in the soil skeleton in the vicinity of the perforation hole for the cased well, we have in every point of the perforation hole wall

$$s_{r'} = -(q + p_w)\left(R_h/r'\right)^2 + q + p(r'),\ \ s_{z'} = q + p(r')$$

$$s_{\varphi'} = (q + p_w)\left(R_h/r'\right)^2 + q + p(r') \tag{1}$$

R_h is the perforation radius, r' is a distance from the well wall. Thus, stresses along the surface of the perforation in a cased hole are constant and equal (assuming in [1] $r' = R_h, p(r') = p_w$)

$$s_{r'} = 0,\ \ s_{z'} = q + p_w$$

$$s_{\varphi'} = 2(q + p_w) \tag{2}$$

3.2 Stress Condition in the Vicinity of a Perforation in an Open Hole

In this case, the perforation hole will not be in an external stress field from rock pressure in the depth of the formation q, but in an uneven stress field from an open hole, in which the perforation hole is shot through. In turn, the stress field around the open hole is determined by the rock pressure in the depth of the formation q and the pressure in the well p_w.

Then, at the upper point N of the vertical section of the perforation hole, to change the effective stresses depending on the distance from the well axis, we have [11].

3.3 Stress State in the Vicinity of a Perforation in an Open Hole

In this case, the perforation hole will not be in an external stress field from rock pressure in the depth of the formation q, but in an uneven stress field from an open borehole. In turn, the stress field around the open hole is determined by the rock pressure in the depth of the formation q and the pressure in the well p_w.

Then, at the upper point N of the vertical section of the perforation hole, to change the effective stresses depending on the distance from the well axis, we have

$$s_{r'}(r) = 0,\ \ s_{z'}(r) = -(q + p_w)(R/r)^2 + q + p_w$$

$$s_{\varphi'}(r) = 3(q + p_w)(R/r)^2 + 2(q + p_w) \tag{3}$$

It can be seen from [3] that stresses along the surface of the perforation hole vary depending on the distance from the well.

$$r = R,\ s_{r'} = s_{z'} = 0,\ s_{\varphi'} = 5(q + p_w) \tag{4}$$

$$r = 2R,\ s_{r'} = 0,\ s_{z'} = 3/4(q + p_w),\ s_{\varphi'} = 11/4(q + p_w) \tag{5}$$

Relations [2], [3]–[5] show that the concentration of the maximum effective stress $\alpha = s_{\varphi'}/q$ on the surface of the perforation hole for the case of an open hole is much higher than for the case of a cased hole. So, $\alpha = 2$ on the entire surface of the perforation in a cased well in the case complete drainage of the well ($p_w = 0$), a the same time he value α exceeds 2 on the entire surface of the perforation in an uncased well. On the wall of the well at $r = R$, the concentration is maximum ($\alpha = 5$) and decreases gradually with increasing a distance from the well wall.

On the basis of relations [2] and [3], for the conditions of the studied field, loading programs simulating the change in stresses on the surface of perforations in cased and uncased wells with a decrease in pressure at their bottom p_w were compiled. In the experiment with an open hole, the stress change was simulated at a point on the surface of the perforation hole, which was by a distance $r = 1,25R$ from the well axis.

During the experiments, the strains of the specimens were measured in three directions and the change in their permeability in the bedding plane was recorded.

4 Specimens Test Results

Ten specimens from the studied field were tested at the TILTS setup according to the above programs. During tests according to a program that simulates a change in stresses in the vicinity of a perforation hole in a cased borehole, the specimens were deformed elastically without increasing the permeability even when reaching the maximum stresses corresponding to complete drainage of the well are reached.

A different picture was observed when testing the specimens using the “open hole perforation” program, which simulates the stress change at a point on the surface of the perforation hole at a distance $r = 1,25R$ from the well axis. Figure 1 shows the strain curves of one of the specimens obtained in the experiment and the change in its permeability.

Figure 1a shows that when simulating on the TILTS the conditions that occur in the vicinity of an open wellbore with a decrease in pressure in it, the specimen was deformed elastically up to stress $s_2 = 120$ MPa, and then its inelastic deformation began, and the sample collapsed at $s_2 = 126$ MPa. Since the stress s_2 applied to the specimen in the loading unit of the TILTS corresponds to the absolute value of the circumferential stress $\left|s_{\varphi'}\right|$ in the vicinity of the perforation hole, we have $p_w =$

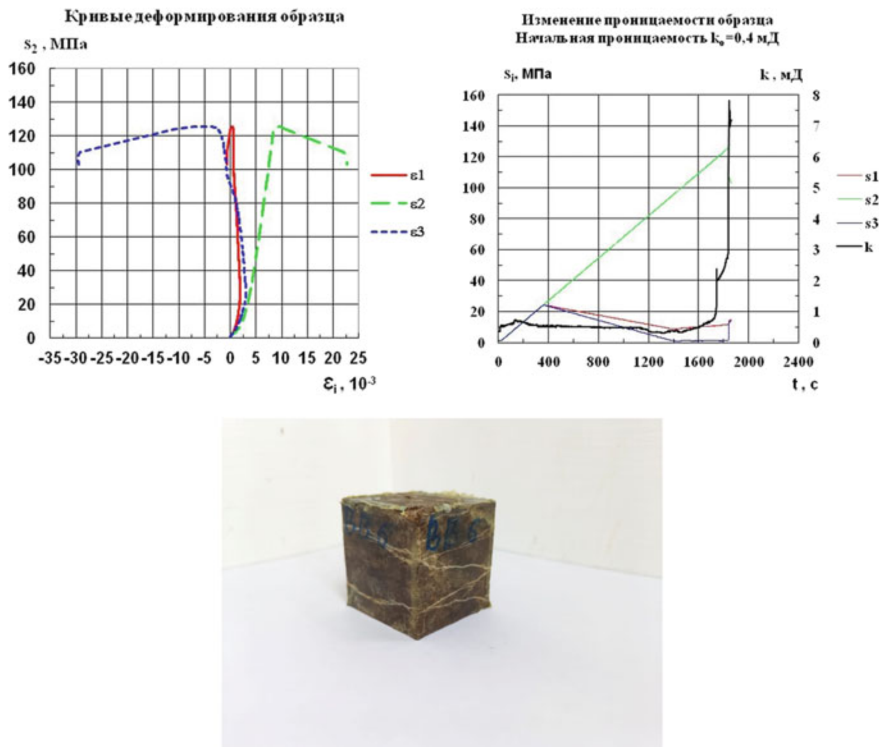

Fig. 1 Specimen test results using the “open hole perforation” program; a—strain curves, b—change in the permeability of the specimen during the experiment, c—a picture of the specimen after testing

$|q| - (25/98)s_2$ from expression [3]. Accordingly, the start of inelastic deformation of the specimen corresponds to a pressure at the bottom of the well of $p_w = 9.6$ MPa, and the destruction of the specimen corresponds to a pressure of $p_w = 8.1$ MPa.

The initial permeability of the specimen was 0.4 mD, and it increased to 7.8 mD in the result of its destruction in the process of the loading the specimen, Fig. 1b.

Figure 1c shows a photograph of the sample after testing. It clearly shows the system of cracks formed in the sample, which led to an increase in its permeability.

5 Conclusions

A number of practically important conclusions follow from the results obtained.

1. From practice, it is known that lowering the pressure at the bottom of cased wells with a perforated bottom to minimum possible value does not lead to an increase

in well production, especially in fields with low-permeability reservoirs,. A similar pattern is often observed for open wellbores.

2. A preliminary perforation of the open hole can help for such conditions, since in this case, as follows from [3]–[5], compressive stresses arise in the vicinity of the perforation hole, which significantly exceed the stresses at other bottomhole designs.

   This conclusion is confirmed by the results of the experiments presented in the work.

   It follows from [3]–[5] that large concentrations of stresses on the surface of a perforation hole in an open hole occurs no more than at a distance of 2–3 radii of the well from its axis. From the above, an important conclusion follows regarding the optimal shape of the perforations in an open hole for the implementation of the DUF method—they should be rather short, but wide. In this case, the effect of their use will be maximum.

3. Summarizing the results of experiments and mathematical calculations, we can conclude that the geomechanical approach using physical modeling of deformation, destruction and filtration processes in productive formations can serve as a basis for the development of new efficient and environmentally friendly technologies for increasing the productivity of oil and gas wells and increasing oil recovery in low-permeable formations.

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