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Research Article

Experimental Study of The Influence of Fluid Flow Rate on The Risk of Rock Destruction

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Abstract The stresses acting in the vicinity of wells have a significant impact on the flow properties of the reservoir and, as a result, on the flow rate of oil wells. The magnitude of such stresses depends on the deformation properties of the rock and on the oil pressure at the bottom of the well. In this work, an attempt to study the effect of flow fields (formation flow rate, well flow rates) on rocks in near-wellbore zones was performed. For this purpose, the correlation of such indicators as the fluid flow rate and the risk of destruction of the rocks of the productive deposits of one of the gas fields were experimentally studied. The experiments were performed on chosen core samples with quite wide range of flow and volumetric reservoir properties. It was concluded that the rock samples of the productive deposits of the studied formation do not collapse under the influence of pressure gradients corresponding to the design flow rates.

1. Introduction

When the pressure in the well decreases, the shear stresses in its vicinity increase, which under certain conditions can lead to the destruction of the rock near the well [1][2]. At the same time, the permeability in the destroyed area increases sharply, which increases the flow of oil from the reservoir into the well. Today, one of the problems of the development and operation of natural hydrocarbon deposits is the reliable accounting of geomechanical processes in the development project [3][4].

The use of geological-flow-strength models makes it possible to assess the likelihood of subsidence of the earth's surface over the developed deposits, to determine the stress-strain state in the section of the proposed drilling of wells and to predict the deterioration of the filtration capacity of the reservoir due to its destruction and clogging [5][6].

When performing geomechanical calculations, in addition to elastic properties (Poisson's ratio, Young's modulus), the strength criterion is laid down in the model. For its formulation, it is necessary to conduct special strength tests under conditions of triaxial loading [7][8]. However, the necessary amount of experimental data is not always available to create a reliable geomechanical model. In this case, we have to be content with an experimental assessment of the maximum permissible loads. Modern geological and flow models make it possible to perform a joint calculation of flow and geomechanical fields, taking into account their mutual influence [9][10]. Thus, a separate issue is to study the effect of flow fields (flow rate, well flow rates) on rocks in near-wellbore zones.

2. Methodology

For this purpose, the correlation of such indicators as the fluid flow rate and the risk of destruction of the rocks of the productive deposits of one of the gas fields were experimentally studied. The experiments were carried out under conditions of equiaxial and non-equiaxial loading of the skeleton of a dry or partially water-saturated reservoir rock in a wide range of flow-volumetric properties (Table 1).

Table 1: Flow-volumetric and lithological characteristics of the studied samples: K - absolute permeability, φ - porosity

№ sample	Well	Formation	K, md	φ, %	Lithology
1	3	1–2	10,1	22,8	Fine-grained sandstone, silty
2	3	1–2	15,0	24,7	Siltstone
3	3	1–2	16	24,9	Siltstone
4	3	1	22	24,4	Sandy siltstone
5	3	2	24	24,7	Fine-grained sandstone, silty
6	1	1	26,6	20,4	Fine-grained sandstone
7	1	2	47,4	21,5	Fine-grained sandstone
8	3	2	196	24,8	Fine-grained sandstone
9	3	2	248	24,1	Fine-grained sandstone
10	3	2	293	24,3	Fine-grained sandstone
11	3	2	308	24,9	Fine-grained sandstone
12	3	2	346	25,1	Fine-grained sandstone
13	3	3	377	23,8	Medium-fine-grained sandstone
14	3	3	506	24,3	Medium-fine-grained sandstone
15	5	2	931	25,9	Sandstone fine-medium-grained, brownish-grey
16	5	2	1135	26,7	Sandstone fine-medium-grained, grey
17	5	2	3144	28,7	Sandstone, coarse-medium-grained, brownish-grey

To assess the possibility of reservoir destruction in the near-wellbore zone, where the drawdown reaches its maximum values due to the pore pressure gradient arising during the filtration of fluids[11][12], experiments were conducted using a special unit (Fig. 1) to simulate the design flow rates of wells.

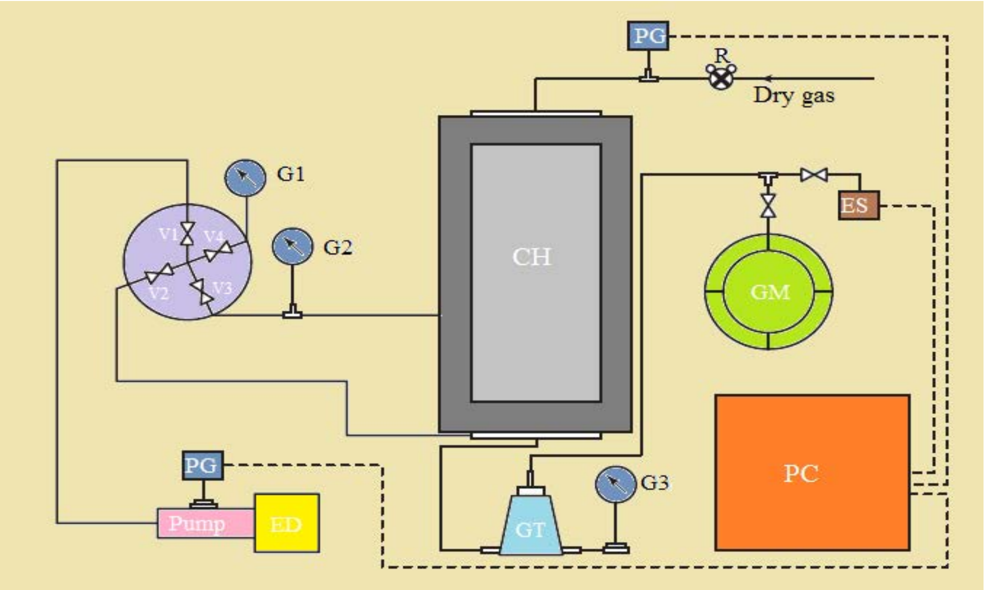

Figure 1: Installation diagram: R - regulator; V1 – V4 - valves; G1 – G3 - manometers (pressure gauges); PC - personal computer; GT - glass trap

The unit (see Fig. 1) is designed to measure gas permeability in reservoir conditions and to determine the conditions for the destruction of core samples at different ratios of radial (lateral) and axial stresses, as well as at different pore pressure gradients. The experimental installation consists of a special type core holder ZK-8 (CH), a crimping pressure system based on an automated high-precision single-plunger piston pump with an electric drive LN1-700-100 (ED), a flow rate determination system, a system of connecting pipes, valves, high pressure gauges(G) and a precision gauge of overpressure MIDA-13P (DD).

The core holder ZK-8 allows us to independently create axial and radial loads of up to 60 MPa on a standard core sample and flow the fluid in the axial direction (Fig. 2).

The pump LN1-700-100 is equipped with its own pressure sensor and operates in the mode of maintaining a given flow rate (in the range of 0.001–25 ml / min) and pressure (up to 70 MPa). The volume of the cylinder is 100 ml. At flow rates less than 1000 ml / min, the gas flow rate was determined using high-precision electronic sensors MKS 179A-21951 (ES), and at high flow rates, a GSB-400 gas meter was used (GM) . In the experiment, dried air with high linear velocities and large pressure gradients (up to 30 MPa/m) was flowed through a core sample at an effective voltage. The studies were carried out on cylindrical samples with a diameter and a length of 30 mm. The pressure drop at the inlet and outlet (ΔP) of the core holder reached 1 MPa.

The moment of destruction of the reservoir rock relative to a given linear flow rate was supposed to be recorded by a sharp drop in pressure in the hydraulic system, as well as by the extreme dependence of the sample permeability on the pressure gradient [13][14][15].

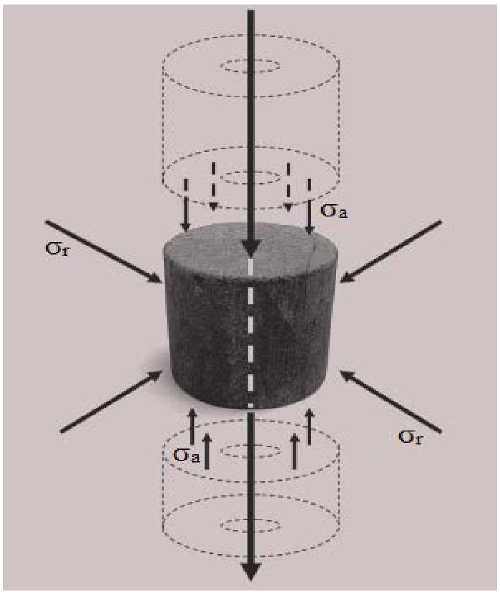

Figure 2: Loading scheme of the rock sample: σ_a- axial stress; σ_r - radial stress

In parallel with the permeability measurements, the control of sand removal from the sample was carried out at various flow modes into a special glass trap (L) located at the outlet of the core holder, which ensured the separation of the gas flow from suspended particles formed during rock destruction. By the presence of rock particles ("sand") in the trap, it is possible to judge the beginning of the destruction of the core sample.

3. Results and discussion

Two series of experiments were performed. In the first series, core samples dried to constant weight were under equiaxially loading (effective stress was modelled as the difference between the overburden and formation pressures $P_{eff} = P_{ov} – P_{fm}$): $\sigma_a = \sigma_r = 22$ MPa. In the investigated range of gas flow velocities Vg (up to Vg = 53 m / min), none of the core samples was destroyed. Sand removal was also not observed. A collection of samples was studied in the range of permeability values K = 10 – 3150 md and porosities m = 20.4 –28.7% (see Table 1).

So, for a projected horizontal section of a well with a length of L = 500 m and a radius of R = 12.25 cm, which penetrates a gas condensate reservoir and operates with a flow rate Qw in the range of 2–3 million m3 / day, the range of gas flow velocity in reservoir conditions will be:

$$Vg = \frac{Q_g}{A_w} = \frac{Q_g}{2\pi RL} = 0{,}022 \ldots 0{,}033 \quad m/min \tag{1}$$

Where Qg is the gas flow rate under reservoir conditions (formation pressure P_{fm} = 22 MPa, formation temperature T_{fm} = 125 °C); Aw is the area of the well site.

The range of Qg values was estimated using the equation of state of an ideal gas[16][17]:

$$Q_g = Q_w \frac{P_{st}\, T_{fm}}{P_{fm}\, T_{st}} = 12{,}1 \ldots\ldots 18{,}2 \quad Mm^3/day \tag{2}$$

Where; P_{st} is the pressure under standard conditions = 0.1 MPa and T_{st} is the temperature under standard conditions = 25 °C.

In the single-phase flow approximation, it is also possible to estimate the linear oil flow velocity Vo, which corresponds to the experimental pressure gradients that occur during gas flow. To do this, knowing the ratio of fluid viscosities and assuming that the permeability is the same for both phases and corresponds to the absolute one, we can obtain the range:

$$V_o = \frac{\mu_g}{\mu_o} V_g = 0{,}092 \ldots\ldots 0{,}14\ cm/min \tag{3}$$

Where; μ_o is the dynamic viscosity of oil = 0.43 cp and μ_g is the dynamic viscosity of gas (air) = 0.018 cp.

It can be seen (Table. 2), that the experimentally obtained maximum flow velocities for the studied group of samples exceeded the design ones (see formulas (1) and (2)) by at least 150 times, and by a maximum of 2400 times. Thus, in the first series of experiments, no rock destruction was recorded, even when the design flow velocities were exceeded by two or three orders of magnitude.

Table 2 : Linear gas flow rate: ΔP / L - pressure gradient; V_g is the maximum linear velocity obtained in the experiment gas flow ; V_o - calculated maximum linear oil flow rate; S_{wr} - fraction in the sample of residual water created by centrifugation

№ sample	Dry sample			Partially water-saturated sample			
	$\Delta P/L$, MPa/m	v_g, m/min	v_o, m/min	S_{wr}, %	$\Delta P/L$, MPa/m	v_g, m/min	v_o, m/min
1	35.4	5.2	0.2	31.6	24.9	4.3	0.2
2	34.5	8.3	0.3	37.0	21.5	5.4	0.2
3	35.4	9.0	0.4	34.4	24.2	6.5	0.3
4	30.9	7.1	0.3	23.3	19.9	6.5	0.3
5	34.4	10.1	0.4	33.7	25.2	9.1	0.4
6	37.0	9.5	0.4	6.1	27.9	9.5	0.4
7	34.3	15.2	0.6	–	–	–	–
8	33.4	29.1	1.2	5.8	5.2	24.2	1.0
9	34.6	40.8	1.7	15.2	24.1	34.1	1.4
10	34.2	41.4	1.7	16.3	25.3	41.4	1.7
11	28.0	36.0	1.5	8.9	19.7	42.7	1.8
12	34.1	31.8	1.3	14.2	18.3	40.3	1.7
13	31.4	32.9	1.4	21.6	20.4	45.3	1.9
14	24.7	40.0	1.7	12.1	25.1	43.7	1.8
15	22.6	49.0	2.1	7.8	24.4	49.6	2.1
16	19.2	51.1	2.1	7.3	22.0	46.4	1.9
17	19.2	53.0	2.2	2.2	21.1	115.7	4.8

In the second series of experiments, the influence of non-axial loading and residual water on the strength of reservoir rocks was investigated. It is known that the strength of rocks significantly depends on the type of saturating fluid [18][19]. Thus, it was found that in the presence of an aqueous solution in the rock with a volume concentration of more than 5%, a significant change in the strength properties of carbonate rocks occurs [20][21][22].

To study the effect of residual water on the rock strength, core samples with residual water saturation created by centrifugation at 4500 rpm were placed under conditions of non-axial loading: σ_a = 22 MPa, σ_r = 11 MPa. In the second series (see Table 2) of experiments, none of the samples was destroyed in the investigated range of flow velocities (up to V_g = 116 m / min).

The experimentally obtained maximum flow velocities for the studied group of samples exceeded the design ones by a minimum of 130 and a maximum of 5250 times. The results of the second series of experiments showed that even in more severe (residual water and unequal loading) reservoir conditions at high flow velocities, the destruction of rock samples does not occur.

It should be noted that after centrifugation, some of the samples stratified (cracked) along the bedding (perpendicular to the flow direction). Nevertheless, during the flow tests, the stratified samples were not destroyed, but, on the contrary, there was a compaction of cracks at the site of the initial stratification.

4. Conclusions

Summing up the results of the conducted research, it can be argued that the rock samples of the productive deposits of the studied formation do not collapse under the influence of pressure gradients corresponding to the design flow rates. This conclusion is based on the fact that the studied collection of core material represents a wide range of flow and volumetric properties of productive deposits of the studied area. The influence of residual water and non-axial loading on the strength of the collection under reservoir conditions at high flow velocities is studied. It is shown that the destruction of dry and partially water-saturated rocks did not occur even in the presence of shear stress caused by an uneven load.

It was found that water flow during centrifugation had a stronger effect on the structure of the skeleton of the rock than gas flow at large gradients under reservoir stress conditions. For a more in-depth assessment of the conditions for the onset of destruction of the reservoir rock during fluid flow with design flow rates in the future, it is advisable to conduct another series of experiments under conditions of lower axial stress. Possibly, high compressive axial stresses are the main factor preventing the destruction of samples in the experiment. In addition, it should be noted that in order to fully simulate the stress-strain state of the rock on the well wall, the experiments do not have enough implementation of an independent third loading axis.

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