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Changes in the Physical Properties of Hydrocarbon Reservoir as a Result of an Increase in the Effective Pressure During the Development of the Field

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Abstract

The change in reservoir pressure and its effect on the physical properties of the reservoir under the development of the hydrocarbon fields has always been of great interest to many researchers in the oil industry. One of the tasks of core research is to obtain interpretation models that provide quantitative processing of well logging data. The effects of the change of effective pressure on the reservoir properties of productive reservoir rocks in the simulation conditions of the reservoir are studied. Reservoir conditions were simulated, and under these conditions, the main physical properties of each sample were determined. The field development process was simulated by a decrease in reservoir pressure, accompanied by an increase in effective pressure by 10.0 MPa. This has shown that we can expect a decrease in the average formation porosity (φ) value by 0.05 absolute percent or 0.24%, and a decrease in the permeability (K) by 0.24 md, or 0.14 %. The data on changes in some petrophysical parameters are analyzed from the point of view of their dependence on changes in the effective pressure of the reservoir, obtained in the first approximation of the assessment of these changes.

Keywords: *: Physical properties, Effective pressure, Reservoir pressure, Porosity, Permeability.*

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INTRODUCTION

Reservoir pressure is one of the most important indicators of the development of oil and gas fields. The energy resources of the reservoir at each stage of its development are characterized by the value of the reservoir pressure (P_r). It is known that the development of oil and gas fields, as a rule, is accompanied by a decrease in reservoir pressure[1][2]. Subsequently, depending on the mode of operation of the hydrocarbon field, annual production volumes, etc. different trends can be observed in the change in reservoir pressure. Among which are the changes in the physical properties of the reservoirs [3][4]. The pressure of the overlying rocks (rock pressure) does not change in this case, but a redistribution of stresses occurs, i.e. Part of the load that the fluid contained in the pores of the rocks took on, is absorbed by the matrix of the rock. Thus, a decrease in reservoir (pore) pressure and an increase in effective pressure (P_{eff}) are the main reasons for changes in the physical properties of reservoirs accompanying the development of hydrocarbon fields [5][6]. The effective pressure, in this case, refers to the difference between the geostatic (overburden) PG and the pore (reservoir) pressure P_r [7][8]:

$$P_{eff} = P_G - kP_r$$

Where the value of the P_G is determined by the thickness and density of the overlying rocks; k is a coefficient that depends on the properties of the rock matrix and its composing minerals (usually k = 1).

EXPERIMENTAL WORK

Studies of changes in the physical properties of the reservoir when modeling the increase of P_{eff} were carried out on rock samples, taken from an oil and gas condensate field.

Reservoir conditions were simulated, and under these conditions, the main physical properties of each sample were determined, such as porosity, the compressibility of the pore space, formation resistivity with the calculation of the Formation factor, and the speed of propagation of elastic waves with the calculation of elastic coefficients (Poisson's ratio, Young's moduli, shear stress, and volumetric compression). In total, more than 100 samples of terrigenous deposits of this field, represented by various sandstones and siltstones, from 4 wells (sampling depth of 2400-2700 m) were studied. The range of porosity of the investigated rock samples was from 2.90–33.4%, the range of gas permeability was 3–1600 md under atmospheric conditions.

The field development process was modeled by increasing P_{eff} from 37.0 to 47.0 MPa (such an increase is observed with a decrease in P_r by 10.0 MPa). The data obtained during the study of the core material for each petrophysical parameter were grouped by the corresponding pressures during processing. Further, from the entire array of measurement results of petrophysical parameters, the maximum and minimum values were separated and the average values were calculated, after which the graphs of the dependence of the average values of the investigated physical properties on the change in P_{eff} in the range of 2–37.0 MPa were plotted (see Fig. 1–8 below). P_{eff} equal to 37.0 MPa was conventionally adopted at the beginning of the development and accordingly the values of the parameters, or physical properties, at P_{eff} = 37.0 MPa, were taken as 100% [9][10]. Then, by approximating the dependence of the change in the average values of each parameter (physical properties) on P_{eff}, the values of the parameters were obtained at P_{eff} = 47.0 MPa, i.e. their expected values are displayed with a decrease in P_r by 10.0 MPa.

The approximation method used is the least square method with the calculation of R^2 - the correlation coefficient [11][12]. Despite the common principle of plotting all graphs, the obtained dependencies are unique for each petrophysical parameter.

RESULTS AND DISCUSSIONS

Figure 1 shows the changes in the formation porosity φ with increasing P_{eff}. It is shown that at P_{eff} = 47.0 MPa, the average (φ_{avg}) value of porosity will decrease by 0.049 absolute percentage, or 0.24%, relative to the φ value at P_{eff} = 37.0 MPa.

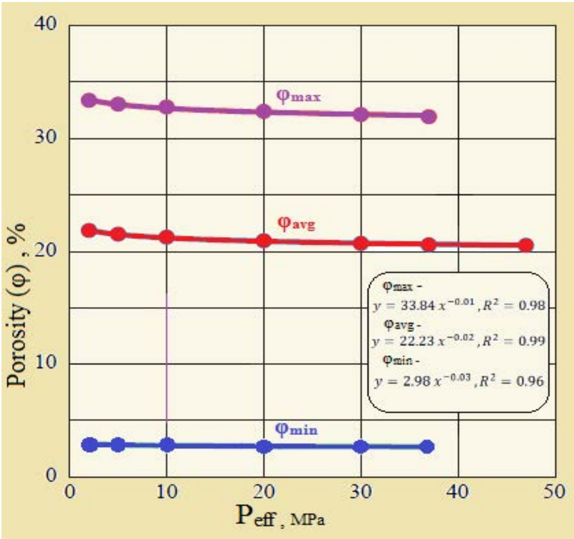

Fig. 1: *Effect of the effective pressure on the formation porosity: R^2 is the correlation coefficient*

This study also considered the dependence of the change in the bulk density ρ on P_{eff} (Fig. 2). The expected increase in the average (ρavg) value of density with a decrease in P_r by 10.0 MPa was 0.00071 g / cm^3, and the relative change was 0.034%.

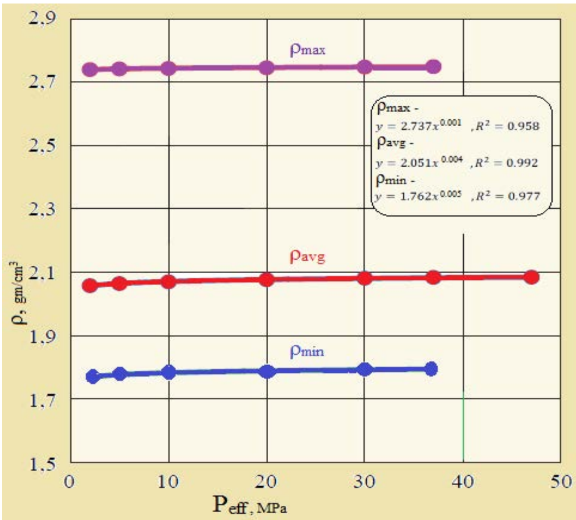

Fig. 2: *Effect of the effective pressure on the formation bulk density*

The change in φ depends on the compressibility of the pore space C_p. The influence of the growth of P_{eff} on C_p is shown in Fig. 3. Approximation of the dependence of the average ($C_{p.avg}$) values of pore volume compressibility showed that with a decrease in P_r by 10.0 MPa, a decrease in $C_{p.avg}$ can be expected from 1.60 x10^{-4} to 1.43x 10^{-4} 1 / atm, or by 1, 67 x 10^{-5} 1 / atm, which is 10.5% of the C_p value at the initial P_{eff} = 37.0 MPa.

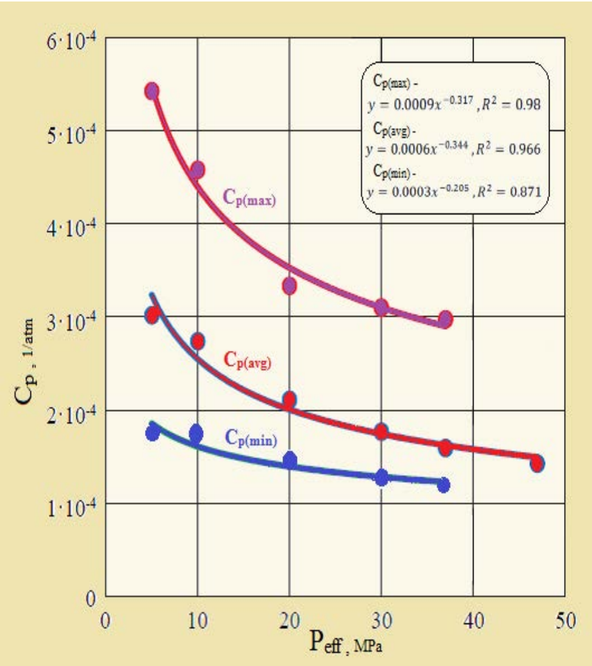

Fig. 3: Dependence of the compressibility of the pore space on the effective pressure

Figure 4 considers the effect of an increase in P_{eff} on the specific electrical resistance (resistivity), which is important in the complex of standard logging of wells. The dependence of the average (R_{avg}) values of the resistivity on P_{eff} is approximated by an exponential curve. As a result of the approximation, it was found that with a decrease in P_r by 10.0 MPa, an increase in resistivity (R) is expected from 2.497 Ohm-m at P_{eff} = 37.0 MPa to 2.654 Ohm-m at P_{eff} = 47.0 MPa, or by 0.157 Ohm-m, which represents a relative growth of 6.3%.

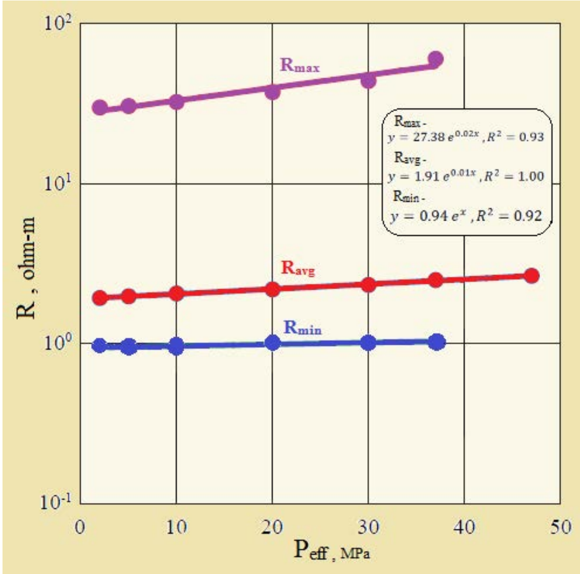

Fig. 4: Effect of the effective pressure on the electrical resistivity

The result of the interpretation of the electrical logging data is to obtain the dependence of formation porosity (φ) on the Formation factor F [13][14][15]. The influence of P_{eff} on F is shown in Fig. 5. Based on the dependence of the average values of F on P_{eff}, the value of F was obtained at P_{eff} = 47.0 MPa as expected with a decrease in reservoir pressure P_r by 10.0 MPa. The absolute increase in F was 1.264, and the relative growth was 6.4%.

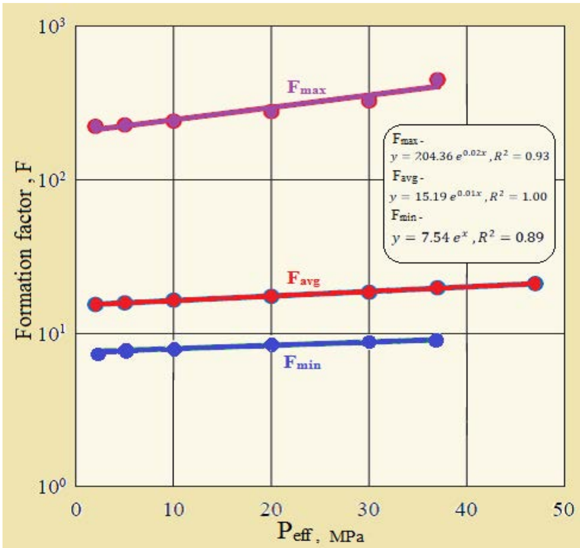

Fig. 5: Dependence of the formation factor on the effective pressure

In the composition of well logging methods, an important place is occupied by acoustic logging, which makes it possible to determine the interval time or the velocity of propagation of elastic waves [16][17][18]. Hence, the study considered also the effect of effective pressure on the velocity of propagation of longitudinal (Fig. 6) and lateral (Fig. 7) elastic waves.

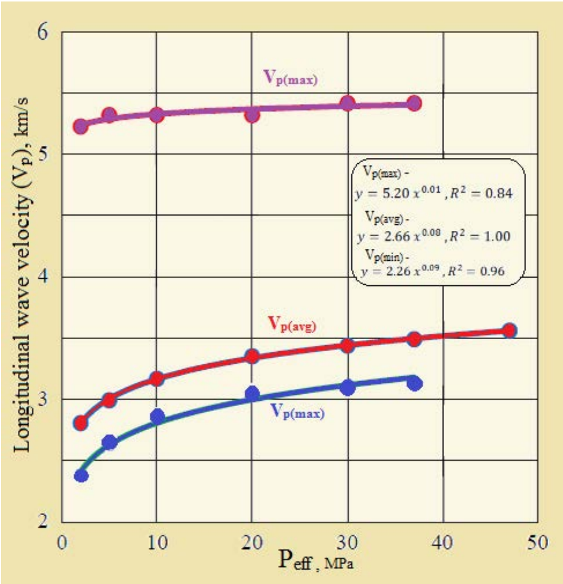

Fig. 6: *Change in the velocity of longitudinal waves with an increase in the effective pressure*

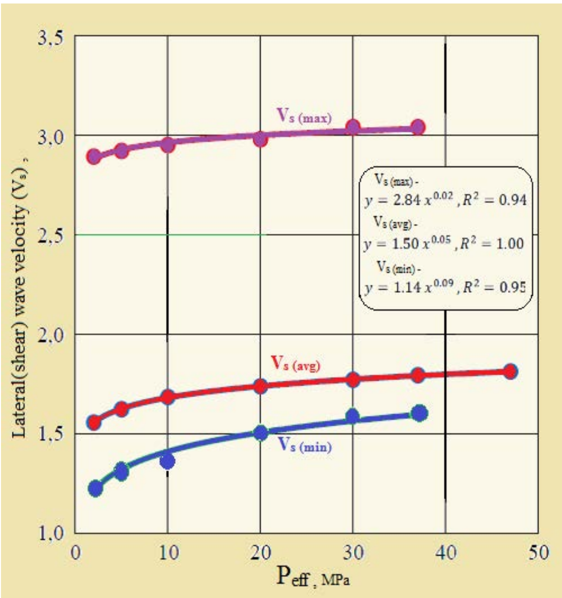

Fig.7:*Change in the velocity of lateral waves with an increase in the effective pressure*

By approximating the dependence of the average values, the expected values of propagation velocities of elastic waves were obtained with a decrease in P_r by 10.0 MPa. Longitudinal velocity on average increased by 0.070 km / s, and the relative change was 2.0%. Lateral velocity on average increased by 0.0187 km / s, the relative change was 1.045%.

From the known values of the velocities of propagation of elastic waves in rocks and the density of these rocks, it is possible to calculate the values of such elastic moduli as Young's modulus, Poisson's ratio, shear modulus, and bulk modulus[19][20].

A decrease in reservoir pressure during field development will not only lead to a decrease in the porosity value but will also reduce the gas permeability values[21][22].

The performed experimental studies made it possible to obtain the dependence of the gas permeability coefficient (K) on P_{eff} (Fig. 8).

By approximating the dependence of the average K values, the expected values of the gas permeability of rock samples were obtained with a decrease in reservoir pressure by 10.0 MPa.

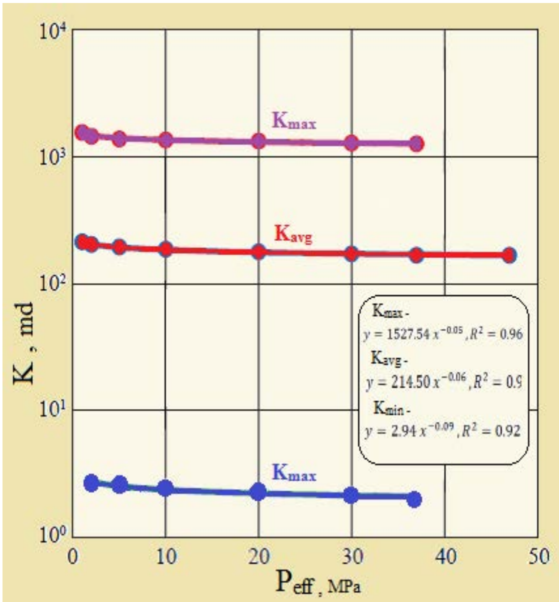

Fig. 8 : *Change in gas permeability with increasing effective pressure*

The gas permeability of the studied rock samples, when modeling an increase in the effective pressure by 10 MPa, decreased on average by 0.242 md, and the relative change was 0.144 %, i.e., the gas permeability naturally decreases by a rather small amount. The largest absolute changes in gas permeability occur in samples with high permeability, but they do not exceed 1.0% of the gas permeability at 37 MPa. Table 1 presents a summary of changes in the average values of the studied petrophysical parameters with an increase in effective pressure by 10 MPa.

Table 1: *Absolute and relative changes in petrophysical parameters with an increase in Peff from 37 to 47 MPa.*

Petrophysical parameters	Decrease (↓) / Increase (↑) of parameters	Absolute change	Relative change, %
φ , %	↓	0,05	0,24
ρ , g/cm³	↑	0,0007	0,03
C_p, 1/атм	↓	$1{,}67\cdot10^{-5}$	10,5
R , Ohm-m	↑	0,157	6,3
F	↑	1,26	6,4
V_p, km/s	↑	0,07	2,0
V_s, km/s	↑	0,19	1,0
K, md	↓	0,24	0,14

CONCLUSIONS

In conclusion, it should be emphasized once again: modeling of the field development process with a decrease in reservoir pressure, accompanied by an increase in effective pressure by 10.0 MPa, showed that we can expect a decrease in the average porosity (φ) value by 0.05 absolute percent or 0.24%, and a decrease in the permeability (K) by 0.24 md, or 0.14 %. All changes in the petrophysical parameters were calculated relative to the values of these parameters at the effective (P_{eff}) in the reservoir of 37.0 MPa, the values of which were taken as 100 %. Thus, the data on changes in some petrophysical parameters are analyzed from the point of view of their dependence on changes in the Peff in the reservoir, obtained in the first approximation of the assessment of these changes. The need for additional experimental testing of samples under thermobaric conditions simulating reservoir conditions is noted to clarify these dependencies, which often differ from linear ones. The data obtained can be used both to assess changes in reservoir conditions based on the data of repeated well logging and to assess the degree of change in the productive layers in the process of field development, accompanied by a decrease in reservoir pressure.

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