PROBLEMS AND WAYS OF EFFECTIVE DEVELOPMENT OF DEEP OIL DEPOSITS WITH ABNORMALLY HIGH RESERVOIR PRESSURES

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Abstract. *Currently, due to the reduced fund of prospective structures at shallow depths (2500-3000 m) annually increased amount of discovered and put in development oil deposits lying at greater depths. According to published works in various oil and gas provinces of the world within the depth interval 4500-8100m already being developed more than 1000 fields [1].*

Condition of development of deep-seated deposits of Uzbekistan

Number of deposits at great depths are discovered, including as well in the Fergana depression of the Republic of Uzbekistan, they are confined to different tectonic elements: Maylisu-Karagundayelevation; Southern Transitional Zone and Central Fergana megasyncline. If the development of oil deposits, confined to carbonate reservoirs of horizons V, VII, IX, Paleogene sediments of deposits Kanibadam, Rawat, Varyk, Varyk II, Tergachi, North Kanibadam, can be considered more or less successful, despite the fact that the expected value of the final recovery factor of oil ranged from 0.2 to 0.4, and are far from the desired. A special problem is oil deposits of deep horizons of Neogene sediments with abnormally high reservoir pressures (AHRP) confined to type of terrigenous collectors, mainly sandstones.

As an example, field Gumkhana which entered into exploration in 1968. It is prepared and transferred to deep drilling on the results of seismic work. The structure is the anticlinal fold of northeast strike with dimensions to the reference reflecting horizon (on contour line – 5000 m): length 12 km, width 6 km,the amplitude 150 m.

According to the materials of well logging, Neogene sediments (brick-red sunk (BRS)) have binomial structure. The upper part of conventionally called BRS-1 shows interbedded sandstones and siltstones with clay. According to the study of sludge by means of nuclear magnetic resonance, sandstones BRS-1 have the following parameters: the porosity of 8-20%, averaging 12.5%, the ratio of oil saturation 0.55-0.97, average 0.74.

The lower part of the brick-red suite marked as BRS-2, has a much better reservoir properties. According to complex GRWBRS-2 is a pack of sandstone formations represented by a series of 0.8 to 18 m and porosity coefficient value is changed in a narrow range 0.20-0.22, with an average of 0.21%, the ratio of oil saturation 0.74-0.80, weighted average thickness – 0.76. Characteristic for BRS-1 and BRS-2 is very weak cementation of sandstones. This is evidenced by sand production during the test of wells on a large diameter chokes and results of experimental studies of core samples represented by poorly cemented fine-grained sandstone easily destroyed by low effort.

As of 01.01.2001 on the field drilled 11 prospecting and exploration wells, 7 of which gave oil flows from minor 0.5-4 m^3/day (well №№ 2, 4, 7, 10) to industrial 28.8-57 m^3/day (well №№ 3, 6, 9). Of them is in operation only the well № 2, which is operated since 1976. The remaining wells because of the frequent complications associated with the removal of rock, formation of sand plugs inside the tubing and the annulus, sticking of tubing were eliminated.

At the same time geological and technical activities to prevent and eliminate complications by washing plug and strengthening of bottom zone with resins not yielded the desired results, the effect of which was short-lived. For example in the exploration well № 9 for 8 months complications with plug-formation repeated 10 times, making it unprofitable operation.

To date recovered from the field only 0.19% of the initial geological reserves,that testifies to extremely low efficiency of its development.

Problems of development of deep-seated deposits

Problems of operation of wells of the fields similar to Gumkhana were previously considered in Refs ofHottmanC.E., JohnsonR.K., EatonB.A.,WooleyG.R., PrachnerW., IrmatovE.K., AgzamovA.H., HuzhaerovB.H. and others [2, 3, 4, 5 etc.].

Inparticular, EatonB.A. on the results of his researches and experience gained offers the reservoirs divided into three classes – the "good", "bad" and "nasty" by the following characteristics: size of reservoir, recoverable reserves; porosity, permeability, pressure and temperature gradients; tendency to contraction; stresses in the rock matrix and the strength of the latter; economic performance of drilling and production. In doing so, to the "good" he attributes – the reservoir, providing adequate flow to the wellbore and economic viability or profitability, to the "bad" – the reservoir, devoid of the good characteristics, but still preserving the quality of the economic viability or profitability; to the "nasty" – the reservoir,lacking of most features and not providing commercial oil, operation of wells with such reservoirs is associated with increased risk, high cost, overcoming difficulties and requires efficient technologies [2].From the results of the above work it follows that for a correct evaluation of the technical and economic performance of field development occurring at great depths, and reducing financial risk is particularly important forecast reliability of properties of reservoir rocks.

EatonB.A. suggested in the work [6] one of the approaches for the classification of reservoirs. Based on the aggregation rate of hydrocarbon production of wells of a large array of many fields, he proposed to consider reservoirs as:

- "good"to a depth of approximately 600 m below the upper boundary of the AHRP;
- "bad" in the range of 600-1500 m below the upper limit AHRP;
- "nasty" at depths greater than 1500 m below the upper boundary of the AHRP.

Thus, the depth of the producing horizon toward the top boundary of the abnormally high pressure is a statistical parameter adopted for the classification of reservoirs.

The average depth of the productive layers of the Fergana basin deposits varies from 500-600 m in cutoff areas and up to 6-7 km in its central part that allows us to trace changes in the many properties of reservoirs.

Assessment of volume density and porosity of rocks-collectors

Using the same approaches and instructional techniques used in the papers [2, 3, 6] we evaluated some mechanical and reservoir properties of reservoir rocks of productive horizons of fields of the Fergana Basin.

Fig. 1 shows the curve of change in the average of bulk density of sandstones with depth of occurrence of the horizons, which is almost identical with the curve obtained from wells in Louisiana, from [6].

Change in the average bulk density of the sandstones (ρ_{dens}) from occurrence depth of horizons (L) is well described by the relation

$$(\rho_{dens}) = a(b - c^{-cL}), \tag{1}$$

wherea, b, c – coefficients numerically equal to a = 1.338192; b = 1.853672; c = 0.000902.

To establish the upper limit of the zone of anomalous reservoir pressure dependences of the initial reservoir pressure of the average occurrence depth were construed for all industrial productive horizons, one of which for horizon III of Neogene and Paleogene deposits horizon IV shown in Fig. 2. Analysis of these dependences shows that the upper limit of abnormally high reservoir pressure in the Fergana basin extends to a depth of 1900 m and approximately 1,000 m higher than the set reservoir temperature on the deposits of Louisiana. This difference can be attributed to various causes and conditions of abnormally high reservoir pressures. If used to classify reservoirs proposed by Eaton B.A. approach, then at adopted by the upper border of the Fergana basin AHRP "bad" reservoirs should be expected at depths of productive horizons over 3400 m.

To study the effect of depth, i.e. pressure of upper layers on the reservoir rock properties in the Research Institute of Geophysics under the leadership of G.M. Avchyan and Z.B. Stefankevich on the unit UFS-2 were carried out special studies [11]. In the study of the relative change in pore volume (porosity) ΔVp / Vp of rock pressure of deep-seated rocks of the Baku archipelago water saturated sample was placed in a pressure chamber and gradually was loaded. Measurements were taken sequentially at rock pressure of 2.5; 5; 10; 20; 35; 50; 75 и 100 MPa.

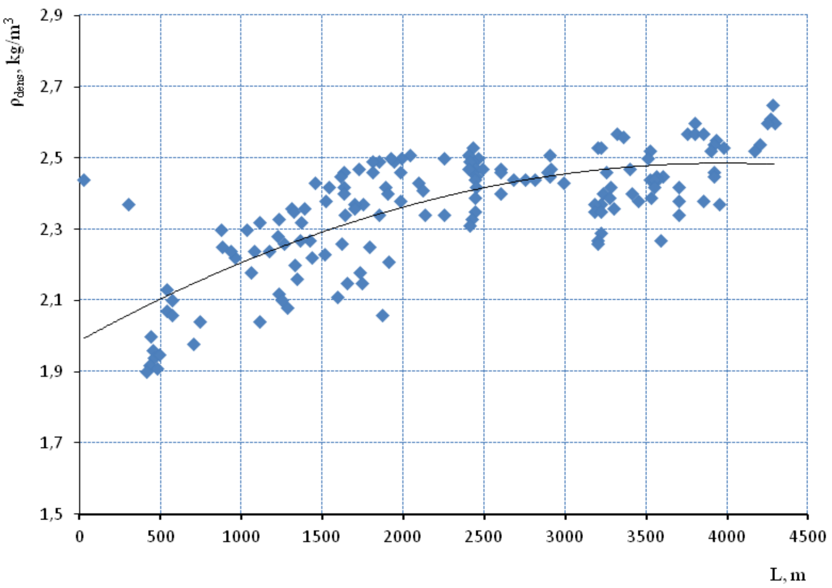

Fig. 1 Change in the average of bulk density of sandstones with depth of the horizons in the conditions of the Fergana oil and gas area

Whereby the relative porosity of these sediments makes 2-3% at rock pressure 10 MPaand 7-7.5% at 100 MPa, that correlates with the results of pilot studies, given in works [2,3,4].

Naturally, the experimental dependencies of the porosity from rock pressure will be closer than the dependencies obtained by means of their correction on the core data, as studies of core samples show the changes in the porosity taking into account the effective rock pressure, which, depending on the abnormal formation pressure may be different in the same reservoir depth. Such studies provide an opportunity to determine the effect of abnormality of reservoir pressure on the porosity and mechanical properties of reservoir rocks.

The paper [11] as well shows the results of studying the effect of depth on the porosity of natural aggregates by processing experimental data on almost 600 samples of rocks of Kala suite of deposits Karachuhur-Zych, Gousany,Peschaniy, Turkyany, Kala, Zyrya, Gyurgyany-sea, Gryazevaya

Sopka, Neftyanye Kamni in the depth interval from 1010 m to 4660 m. With the change in the depth the average porosity of all types of reservoirs decreases from 22.2 to 13.3%, i.e. by some 2.5% for every 1000 m. In the same interval porosity of sand varies from 27 to 15.7%, i.e. by about 3% for each 1,000 meters, and the porosity of clay – from 20.3 to 3.8%, i.e. by 4.5% for each 1,000 m. In studying the effect of depth on the porosity the authors [11]focuse on the core hypsometric confinement factor and not the stratigraphic.

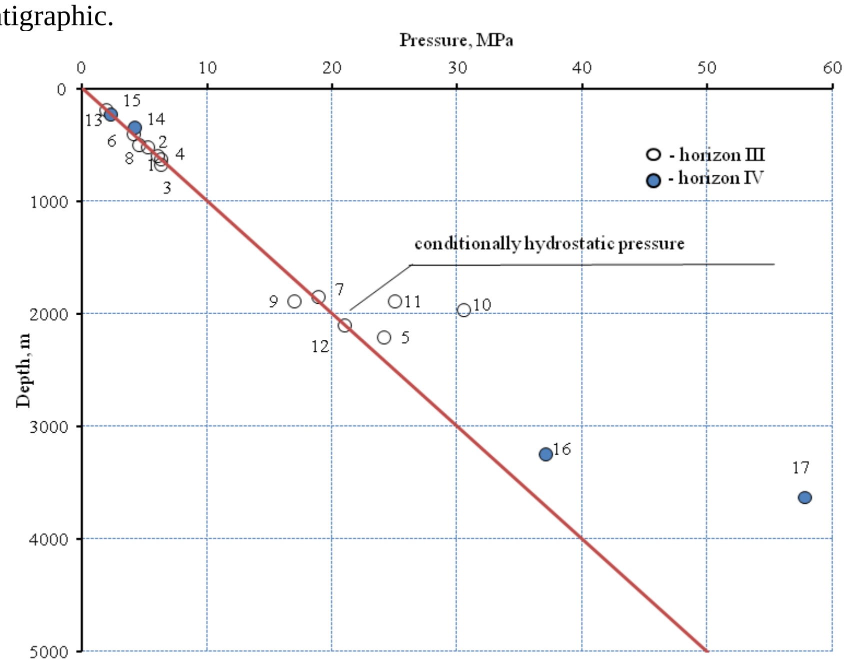

Fig. 2 Dependence between the initial formation pressure and average depth of occurrence of Neocene (III) and Paleocene (IV) rocks in the fields of Fergana oil and gas area: 1 – Andijan (horizonIII); 2 – Khidjaabad (III); 3 – Boston (III); 4 – South Alamyshyk(III); 5 – Khartum (III); 6 – Palvantash (III); 7 – West Palvantash (III); 8 – Changyrtash(III); 9 – Maylisu – IV (III); 10 – Izbaskan (III); 11 – East Izbaskan(III); 12 – East Khartum (III); 13, 15 – Shorsu– IV (III, IV); 14 – Chaur-Yarkutan (IV); 16 – Ravat (IV); 17 – Niyazbek-North Karachikum(IV)

We, whilestudyingthedepthofoccurrence for the porosity, have considered the both these factors.

Fig.3 shows the dependence of porosity of the sandstones of BRS horizon of Neocene sediments from the depth of their occurrence. Despite the obvious spread of porosity values, determined experimentally on core materials, traced the pronounced trend of its decrease with the growth in the horizons' occurrence depth. According to the work [4], in the conditions of [4], progressive loading of sedimentary rocks the porosity to the depth of about 1500m us decreased quite dramatically – by 25-25% towards the surface, and up to depth 3000 m – by 10%. With further increase in depth the open porosity decrease seven slower – by 0.8-1.0% per each 1000m of immersion and on depths 6000-7000mit makes 1-3%.

These findings are in good agreement with the mean values of open porosity, shown in Fig. 3.

Changing the porosity of sandstones from the depth of occurrence of the horizon BRS of Neocene deposits of the Fergana basin is well described by the dependence:

$$m = ae^{bL}, \quad (2)$$

where *a* and *b* – ratios, numerically equal to a = 21.477420; *b* = -0.000486.

For the rocks of Kala suite of the fields in Azerbaijan, it is described the same dependence, but with a slight difference in the coefficients:

a = 29.819076 andb = -0.000130, which predetermined more intense decrease in porosity associated with the lack of objects with AHRP.

Dependency analysis shown in Fig. 2 and 3, indicates their identity and interrelation, in the depth intervals with intense lower porosity rapidly growing volume density of rocks, and in the depth intervals with the slow decline of open porosity decreases also growth of the bulk density of rocks, which is consistent with the currently existing theoretical concepts of conservation of reservoir rock properties and their seals. Natural to assume that the intensity of the decline in the average value of open porosity of rocks below the depth of 1800 m is associated with the appearance of objects with AHRP.

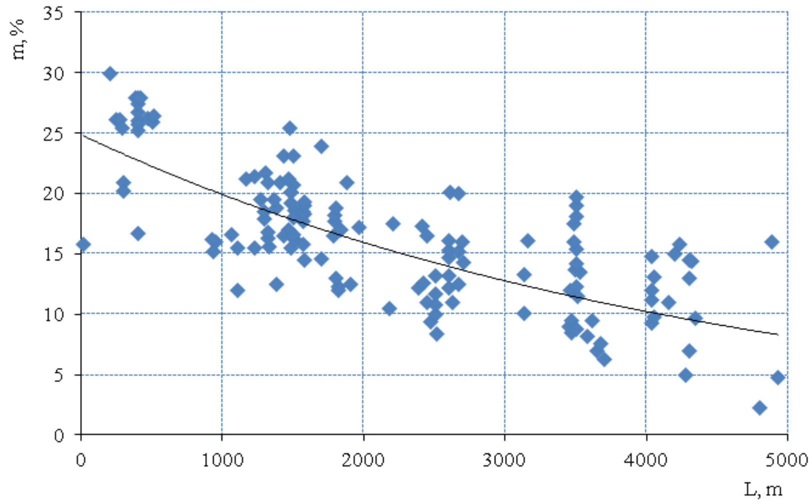

Fig. 3. Dependence of porosity on depth for the horizon of BRS of the Fergana oil and gas area

While maintaining the intensity of reduction of open porosity of rocks established to the upper boundary of the zone of high formation pressure at depths of 6000-7000 m, we would not have reservoirs that provide commercial oil.

Extrapolating the curves obtained in the direction of greater depths, it can be assumed that at a depth of 6000 m porosity of reservoirs be 0.10-0.14. Thus, we can confidently expect at a depth of 6 km availability of collectors with quite satisfactory porosity. As a further change in porosity occurs less intensively at depths greater than 6 km, it probably slightly less.

Prior to entering the field in the development the reservoir rocks are under stress state established over a long geological time due to exposure to the complex forces. One of the defining parameters of the stress state of the reservoir rocks are rock pressure, which conditioned by the weight of the overlying rocks and reservoir pressure. Before the start of oil and gas production the rock pressure and stress arising in the formation are in equilibrium conditions.

Since the pore fluid impacts not on the entire surface of the mineral grains composing the rock, by many researchers the effective rock pressure is determined by the following equation [11,12, 13]:

$$P_{ef} = P_e - n\mathrm{P}_i \qquad (3)$$

where n – coefficient of discharge;P_e – fullnormalstress – geostatic pressure characterizes gravity consolidation;P_i– Neutralstress – represents the backpressure exerted by the pore fluid on the geostatic pressure, and characterizes the filtration consolidation.

ItisshownbyV.M.Dobrynin that [13],

$$\mathrm{n} = 1 - \beta_{sph}/\beta_{rs}\,, \qquad (4)$$

where β_{sph} and β_{rs}– compressibility factors, respectively of the solid phase and rock skeleton.

Coefficient n is “active” portion of the formation pressure when defining the resulting deformations. For clayey rocks normally $\beta_{rs}>>\beta_{sph}$, consequently, n ≈ 1.For the low-porous rocks at high pressures β_{rs} becomes commensurate with β_{sph}, n ≈0. Thus, possible values of coefficient at volumetric deformation of rocks are within 0 to 1.

Components of this normal field of stresses are defined according to the following formulas, used in many theoretical and practical tasks:

- vertically

$$G_z = \rho_{dens}\, g\, L, \qquad (5)$$

- horizontally

$$G_y = G_x = n\,\rho_{dens}\,g\,L, \tag{6}$$

where G_z, G_xиG_y– accordingly the vertical and horizontal components of stresses;ρ_{dens} – meanvolumetricdensityofupperrocks; g – acceleration of free fall; L – average depth of formation occurrence; n – coefficient of lateral thrust.

In practical calculations of the horizontal stress coefficient of lateral thrust roughly estimated by the following formula:

$$n = \frac{\mu}{(1-\mu)}, \tag{7}$$

where μ – Poisson's ratio.

Valueμ for plastic and flowing rock formations approaches 1, for brittle rocks varies within 0.3-0.7, but in practical calculations of oil production processes for sandstones is accepted usually ranges from 0.28 to 0.35.

Assuming the mechanism of nonequilibrium compaction of rocks, the abnormal pressure prevents their consolidation and contributes to the preservation of higher porosity values of reservoirs. At the same time, maintaining higher porosity values leads to decompaction of rocks and they become more brittle than the rocks occurring in the same horizons, but with normal reservoir pressures. In this regard it should be noted that under the considered conditions of the Fergana basin oil deposits occur with normal (K_a=1.0), slightly increased (K_a = 1.1-1.3), abnormally high (K_a = 1.3-2.0) and superhigh(K_a>2.0) rock pressures.

As is known, the relationship between the density of the rock-forming minerals $\rho_м$and the volumetric density of the rock $\rho_п$is expressed thru the porosity (m) as follows:

$$\rho_{dens} = \rho_m (1 - m), \tag{8}$$

i.e. thelargertheporosity,due to the anomalous reservoir pressure the smaller the bulk density of the rock, increasing its fragility, and it becomes more susceptible to mechanical destruction.

Analysis of studies of core materials extracted from various depths and with reservoir pressures shows that in most facilities with normal and slightly elevated reservoir pressures sandstone of the horizon BRS are of the type "strong", and at sites with high and ultra-high formation pressures to type "medium" and "weak" [7]. Inaccordancewithexperimentalworks[8]thevalueoftheultimate strength of sandstones (G_{ult})for these types varies within the "strong" 70-90, «medium» 45-75 and «poor» 30-40 MPa, i.e. earlier made conclusions are proved.

If for analysis of the causes of this phenomenon take the expression (7), then it becomes clear that at the same depths the formation pressure anomality is associated with a Poisson's ratio. In this the growth of abnormality of reservoir pressure results in an increase of Poisson's ratio, i.e. in a more intense expression of deformation of the collector in the horizontal direction.

To confirm these findings,we consider the following example.

Average producing depth is 3500 m and the bulk density of the overlying rocks 2400 kg / m ³. For the case of oil deposit with normal formation pressure P_{form} = 35 MPa, the type of sandstone is "string" with ultimate strength of 80 MPa, and for the case with AHRP P_{form} = 70 MPa and the type of a sandstone is "poor"with ultimate strength of 35 MPa.

From formulas (6) and (7) we get that the vertical (rock) pressure makes 82.32 MPa, and the Poisson's ratiofor the first case is 0.3 and for the second – 0.46.

If the for the determination of condition of rock strength and the prevention of their destruction caused by rock pressure take the ratio as /9,10/:

$$P_{form} - P_{bot} < \frac{G_{ult}}{2} - n(10^{-6}\rho_{dens} g L - P_{form}), \tag{9}$$

then reserve of reservoir pressure for the case of its normal value makes 20 MPa, and for the case of abnormal pressure just – 7 MPa.

Conclusion

As a result of carried our studiesthe following conclusions can be made:

1. in the deep-sunk objects with normal with reservoir pressures due to compaction of rock their reservoir properties are reduced, but their bulk density and fracture resistance are increased. Critical reservoir pressure corresponding to the onset of rock destruction occurs after reduction of the latter, by 50-60% of the initial. If to consider that oil deposit with normal pressures usually have a

pretty good hydrodynamic connection with the water system, reducing of reservoir pressure to a pressure of rock destruction is unlikely;

2. in the deep-sunk objects with AHRP, despite the persistence of relatively high permeability and reservoir properties, they become less resistant to decay. Critical reservoir pressure, conforming to the on set of the rocks destruction, occurs after reduction of the latter lust within 10% of the initial value. Usually such oil deposit sare hydrodynamic isolated from the outer water system that assumes the reduction of the reservoir pressure to the critical value of the rocks destruction in the first years of development. This is one of the reasons for sharp decline in flow rates, ingress of sand due to the destruction of rocks, and in some cases - the complete cessation of inflows of oil;

3. to prevent the reduction of reservoir pressure to a critical the development of fields with AHRP is advisable to carry out from the beginning of the development with maintaining reservoir pressure, preventing its decline below the initial value;

4. at this is more desirable to maintain reservoir pressure by injecting a gas, as many types of sandstones tend to soaking and severe destruction when contacted with water. To reduce the possibility of destruction of rocks in the bottomhole formation zone, it is necessary to carry out geological and technical measures to strengthen it, up to stimulate the fluid influx from the reservoir, because at large pressure drawdown could begin irreversible processes of destruction of rocks with appearance of plastic deformation already in the process of test of the object.

During the stimulation of the influx the bottomhole pressure reduction should be implemented gradually, without abrupt jumps and depression limit value should not exceed 5 MPa;

5. Despite the fact that studies of the stress state of rock not considered a number of factors (tectonic forces, thermal stresses, etc.) the results obtained satisfactorily explain theobserved in practice dynamics of the development of deep-seated oil fields. In this regard, the findings can be used to predict the types of reservoirs, critical downhole and reservoir pressure, evaluation of geological hazards at development of fields of the Fergana Basin and similar deposits in other regions.

REFERENCES

1. Irmatov E.K., Huzhaerov B.H., Agzamov A.H., Features of development of deep-seated oil fields with abnormal-high formation pressure// Uzbek journal of oil and gaz. Specialedition. – Tashkent, 2012. –pp. 106-110.
2. Krayushkin V.A. Oil and gas fields of deep genesis // Oil and gas. - Almaty, 2008.- № 2(44).– Pp.104-115.
3. Eaton B.A. Graphical method predicts geopressuresworld wide //World oil, july, 1976, pp. 100-104.
4. Woley G.R., Prachner W. Reservoir compaction loads on casings and liners//SPE Production Engineering, February, 1988, pp. 96-102.
5. Hottman C.E., Johnson R.K. Estimation of formation pressures from log-derived ahale properties//.Pet. Tech, june, 1965, pp. 717-722.
6. Ben A. Eaton. Using the obtained during drilling petrophysical data to assess the prospects // Oil and Gas Technologies. - Moscow, 1996.– № 2-3. –pp. 15-25.
7. Zakirov A.A. Peculiarities of incompetent rock properties change in the operation of ultra deep wells // Petroleum Engineering. - Moscow, 2005.– № 7. – pp. 21-24.
8. Alekseev Y.F., Ilchenko L.B. Mechanical properties of rocks of Bashkiria oil fields under uniaxial compression and tear. - Ufa, Proceedings of Ufa Research Institute, issue. 16.-1965.pp. 55-71.
9. Ashrafyan M.O., Lebedev O.A., Novykov A.S., Belko Y.A. Improving the reliability of the design of wells bottom in low permeability reservoirs // Oil industry.- Moscow, 1991.– № 1. – pp. 44-46.
10. Baydyuk B.V., Bliznyukov V.Y. Forecasting of the pressure gradient of rocks sustainability when developing the well design // Oil industry, - Moscow, 1987. – № 1. – pp. 6-8.
11. Buryakovskiy L.A., Jafarov I.S., Dzhevanshid R.D. Forecasting of physical properties of reservoirs and caps of oil and gas.- Moscow, Nedra, 1982.p. 200.
12. G.M. Avchyan. The physical properties of sedimentary rocks at high pressures and temperatures.- Moscow, Nedra, 1972.p. 198.
13. Dobrynin V.M. Deformation and changes in the physical properties of oil and gas reservoirs, - Moscow, Nedra, 1970. p. 239.
14. Pavlova N.M. Deformation and reservoir properties of rocks.- Moscow, Nedra, 1975.– p. 183.