Researching the fracturing of the reservoir rocks

S.S. Kurovets*[1]**, *I.V. Artym*[1]*, *I.M. Kurovets*[2]

[1]*Ivano-Frankivsk National Technical University of Oil and Gas;*
15, Karpatska str., Ivano-Frankivsk, 76019, Ukraine

[2] *Institute of geology and geochemistry of combustible minerals of NAS of Ukraine;*
3a, Naukova str., Lviv, 79060, Ukraine

Received: 23.05.2018 Accepted: 08.06.2018

Abstract

Research results of the impact of physical processes upon reservoir characteristics of rocks have been presented. The influence of the radial direction of the filtration flow on the permeability has been studied on cylindrical core samples with a central opening. The influence of the stressed state on the permeability and crackability of rocks have been evaluated

Keywords: *core, fracture, pressure, rock, seam.*

Introduction

Due to the emergence of the possibility of extracting hydrocarbons from the sealed black shale rocks, there is a need for their detailed study. Previously, these strata were considered as oil and source rocks. At present, it has been proved in the world that the deposits enriched in organic matter can be both source and reservoir rocks.

Consequently, there is a need for conducting research work in order to identify specific strata, which can be both source and reservoir rocks. The specified rocks must contain a significant percentage of organic matter. In the Western region of Ukraine these are the rocks of two stratigraphic types of the Oligocene Menilite suite and the Spassk suite of the Lower Cretaceous. This has led to conducting detailed field and microscopic studies of substantiating the presence of a significant amount of organic matter.

The question of researching and searching for the causes of the conditions for the formation of hydrocarbon accumulations in various conditions has now become extremely acute. It is necessary to solve this issue in order to succeed in exploring and researching already existing deposits and successful exploration of new fields of oil and gas. To this end, it is necessary to pay more attention to researching the causes of migration of oil and gas, especially lateral, as vertical migration has been studied in more detail in many scientific works. But it is not a secret that reservoir pressure has a significant influence on the formation of oil and gas accumulations and the reservoir properties of rocks. In order to better understand the range of displacements and the formation of fracture within reservoirs, it is necessary to determine the value of the reservoir pressure that will allow moving hydrocarbons inside the formation (internal migration), but equally important is the study of reservoir pressure values that allow hydrocarbons to move between the layers, in other words it is called external migration. The direction of migration can be predicted and the approximate distance of displacement can be further determined if it is know the value of the formation pressure. In other words, can be predicted places of oil and gas accumulation, which is an extremely important issue for solving the problems of the oil and gas state of our country. It is important to not forget about the effect of formation pressure on reservoir properties of rocks. These properties include porosity and permeability. But fracturing of rocks, which is also a way of hydrocarbon migration and places of its accumulation, is often underestimated. This article is devoted to the research of fracturing and its relationship with formation pressure. After all, high filtration and capacitive properties is the key to the movement, accumulation and formation of oil and gas accumulations. These properties include fracturing of rocks.

Setting of the problem

Geodynamic processes play an important role in the formation of reservoir rocks in sections of sedimentary rocks of oil and gas provinces of the world [1]. That is, the combined processes of deformation of rocks in time and space influence not only their deformation and the formation of structural traps, but also their reservoir properties. A characteristic feature of the distribution of large fields is their association with

* Corresponding author:
grn@nung.edu.ua

the zones of intersection faults. In particular, researching the spatial location of oil and gas reserves in the Pre-Carpathian foredeep showed that their maximum concentrations are associated with the three largest tectonic nodes, with which the Dolyna, Bytkiv-Babchyn and Boryslav deposits are connected [2].

Changes in reservoir properties are mainly related to the geodynamic processes of the Carpathian region. As a result, any sediment can acquire the properties of the reservoir, regardless of its lithological characteristics. Consequently, the reservoir properties of the rock do not have a definite relationship with the material composition, because they depend on two groups of factors: primary factors (genetic), which are related to the material composition of the rocks, and secondary factors – transformation as a result of geological processes. Mechanisms and the influence of these geological processes for different structures are different [3].

On the influence of these factors we can judge by the actual characteristics of capacitive and filtration parameters of productive objects, obtained on the basis of exploitation of the reservoir (flow rate, exploration, hydrodynamic testing of wells, etc.). It should be noted that the successful use of hydrodynamic methods gives good results in the evaluation of capacitance and filtration properties. But this is possible if exact quantities of pressure are determined not only in the oil- and gas-saturated but also in the water-saturated parts of the deposit. The determination of pressure must be carried out both during drilling and systematically during the exploration period. Unfortunately, such measurements are rarely and irregular. Thus, the reservoir pressure was the same before the development of the Menilite deposit in the oil saturated part of all blocks according to the measurements in the wells of the Pasichna deposit. This indicated a single hydrodynamic reservoir, the common conditions and source of traps filling with fluids. The deposit is associated with a linearly elongated asymmetric anticline fold of the III structural layer, which is divided by transverse displacements into three blocks: Starun, Bytkiv and Pasichna. The deposits of oil and gas are concentrated in the lower- and middle-Menilite sediments of all three blocks. Slight inflow of gas was obtained from the Vygoda sediments of the Eocene. The current analysis of the reservoir pressure dynamics in the wells confirmed the unity of the Bytkiv and Pasichna blocks, whereas the Starun block is characterized by a rapid rate of reduction of reservoir pressure indicating small residual reserves, low energy potential of the block and its hydrodynamic isolation from others, and of course , low reservoir properties.

An American geologist D. Sekor studied the physical confirmation of the active influence of fluid dynamical processes on the improvement of capacitive and filtration properties due to the formation of fractures. He studied the conditions for the formation of fractures in the crust under the action of fluids and concluded that hydraulic fracturing can occur in natural conditions, if the pressure of the liquid is close to the formation pressure of rocks. The process of origin of fractures consists of numerous short episodes of their formation, which alternate with longer periods of filling them with fluid due to leakage from the surrounding rocks and subsequent cracking. D. Sekor believes that in most cases the rocks contain sufficient fluid to form fractures in them.

There is another feature of the fractures development in conditions of high pressure, which are caused by underground fluids. During the rock masses fracturing the total area of undisturbed bonds (which separate cracks) is reduced. At the same time, the shear stress increases in the area where the connections are maintained. This is expressed by the ratio derived from the mechanics of rocks:

$$\frac{\tau^{*}-\tau}{\tau}=\frac{m}{1-m}\left(1-f\,\frac{\sigma}{\tau}\right),$$

where τ, τ^* are shear stress without and with taking into account cracks; σ is normal tension, which is equal to hydrostatic load; f is coefficient of friction; m is the coefficient expressed by the ratio of the splitting working area to the total amount of fractures.

This formula is valid for rocks in which there is no fluid. In the case of filling pore and fracturing space by fluid, it should take into account the pressure of porous water p and, consequently, the ratio will be as follows:

$$\frac{\tau^{*}-\tau}{\tau}=\frac{m}{1-m}\left(1-f\,\frac{\sigma-p}{\tau}\right),$$

that is, the relative growth of shear stresses will increase with pore pressure increasing. Accordingly, the increase in fluid pressure contributes to faster growth of the fracture formation in rock strata, including when the pressure is less than geostatic.

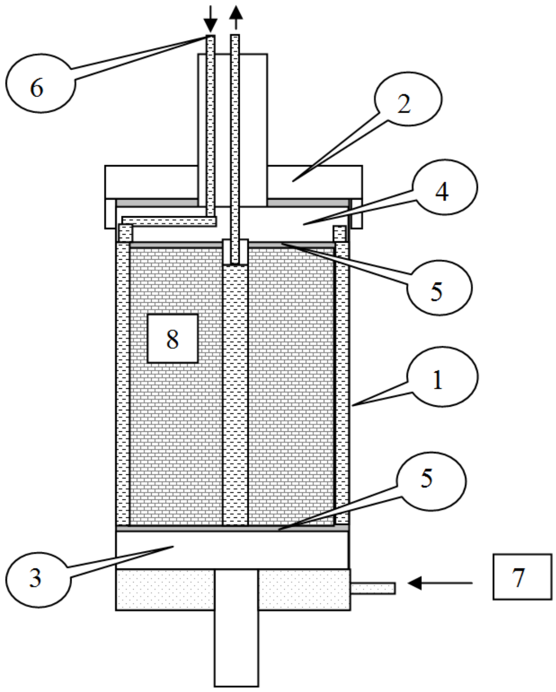
Thus, with increasing of fluid pressure in the pore-fractured space, the frictional shear resistance decreases, which facilitate fracturing of the rock. When the pressure reaches the corresponding value, further development of fractures occurs under the action of a hydraulic fracturing. In addition, physic-chemical processes affect the deformation process. In particular, such an affect has a phenomenon of adsorption decreasing in the strength of solids, which was discovered by Rebinder. The strength of solids depends on the so-called surface energy. It is significantly reduced by the action of surface-active substances that are absorbed on the free surface of a solid and reduce its strength. Under the influence of surface-active substance the shape of deformations changes – the plastic state becomes fragile, which accelerates the destruction. The formation water with sodium chloride, soda and some other salt can act as a hardness reducer.

Consequently, the formation of fractures under the influence of fluids can occur in natural conditions. If fracturing of the rock strata passes under the fluid pressure, then the total area of undisturbed bonds in the rock is reduced. This, in turn, causes stresses increasing and promotes rapid fracturing of the strata not only when the reservoir pressure reaches the values of the formation pressure, but also at lower values of the porous fluid pressure.

Results

Physical processes occurring in different strata, affect both the change in the form of occurrence, and on the properties of rocks. We carried out experimental researches on cylindrical core with a central opening. The core was studied under conditions of water pressure influence on permeability with the change of radial directions of stream jets – convergent and divergent. The pressure was greater on the periphery of the sample than in the opening during the tests of the first type. And in the second case, on the contrary – in the central opening the pressure was greater. In this case, the lines of jets of the stream remained the same as in the previous case, but with the opposite sign. The strain in the rock samples is proportional to the fluid pressure, but in the first case they were as compressible forces, and in the second – as the tensile forces.

An effective method for evaluating the permeability of microfractures and the influence of stress on them is the method of radial filtration. Laboratory researches of low porous fractured rocks are recommended at the installation shown in Figure 1. It is necessary to use large cylindrical samples (D = 40–100 mm, h = 1–1.5 D), with a central opening (D = 10–12 mm). The problem with these researches is that it has to deal with very low fluid consumption (less than 0.01 cm^3/h). Unwanted changes to the samples may cause an increase in fluid flow. In laboratory measurements, the pressure gradient varies within 1–1000 MPa,



1 – camera body; 2 – roller nut; 3 – piston axial load; 4 – piston of the supply of filtering fluid; 5 – polyurethane substrates; 6 – pressure control system and measurement of permeability parameters; 7 – system of creation and adjustment of axial load on the sample; 8 – core sample

Figure 1 – Scheme of the device for radial filtration research

and under natural conditions this value does not exceed 10 MPa. The studies are carried out with a radial convergent and divergent flow of fluid. In the first case, the pressure on the periphery of the cylinder is larger than in the opening of the sample, in the second – on the contrary, while the flow lines remain the same, only their orientation changes to the opposite. The stresses in the rock are proportional to the magnitude of the pressure drop, and in the first case they are caused by compression forces, and in the second – by the forces of tension.

Analysis of the results of radial filtration researches allows us to estimate the rock permeability, depending on its size, character and type of stress state due to changes in the structure and size of microfractures.

The obtained results (Fig. 2) allow us to estimate the influence of pressures on the permeability of the rock sample.

Comparison of the filtration experiments results in rocks with "granular" pores and developed fracturing showed that for the rock of the first type (sandstone), the filtration coefficient Kp is the same for both convergent and divergent water movements. The permeability remained constant, and the results of experiments are completely reversible until the sample began to develop stretching deformations that led to its destruction (sample-1, sample-2, sample-3).

The samples (sample-4, sample-5) are represented by layered rocks, in which interbedding layers of multi-grains siltstones of 1–0.5 mm thickness, with a large number of thin fractures and macro cracks that are parallel to the layers. The permeability of these sitstones sharply decreases with increasing pressure. The process was reversible. As the direction of filtration changed, the permeability quickly increased until the sample destroyed. The compression passed to the stretching gradually. Therefore, on the dependency curve there is no sharp change. In the area of tension, the nature of the process was irreversible, which is clearly noticeable on the curves. But the process became inverse again with the changing to compression.

According to the experiments, it can be concluded that in the rocks with granular porosity the coefficient of filtration depends little on the fluid pressure. It is also worth noting that it decreases markedly with increasing pressure in the presence of microfractures in the rock. These microfractures are elongated in one direction, for example, by stratification. Obviously, changes in the filtration mode from laminar to turbulent occur with pressure increasing in sample fractures. These modes are closed. This reflects the correspondence of the experiment results and the results of research wells. In both cases, it indicates the presence of fractures in the porous area.

The permeability of the samples was experimentally researched by us. This research was conducted at various stressed states. As a result, the process of increasing the microfracturing of the rock during the increase in load was discovered. This increase occurs prior to the appearance on the test sample of external signs of destruction based on the

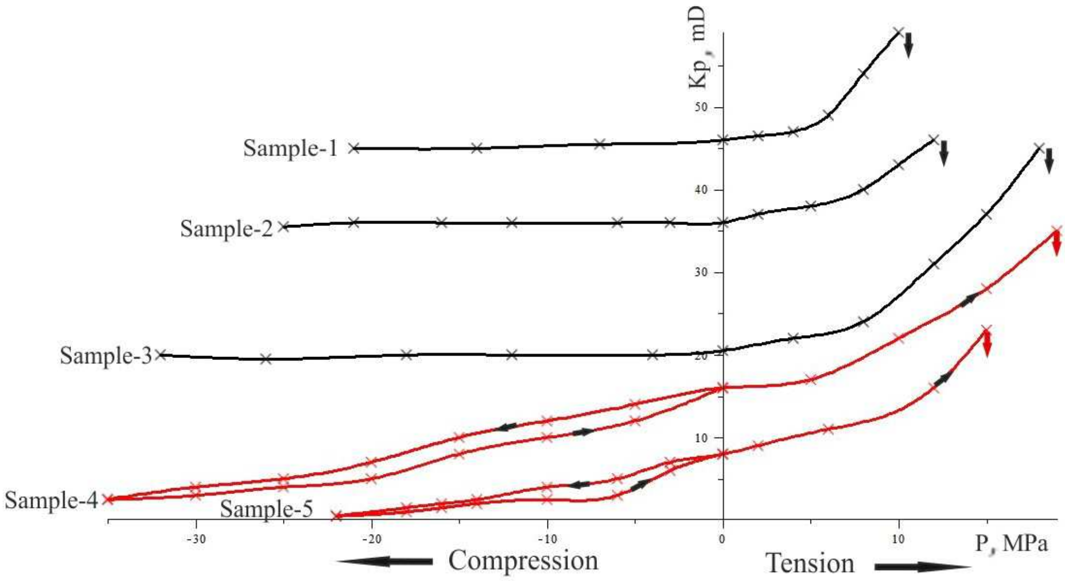


Figure 2 – Rock samples with different type of pore space for radial filtration research results

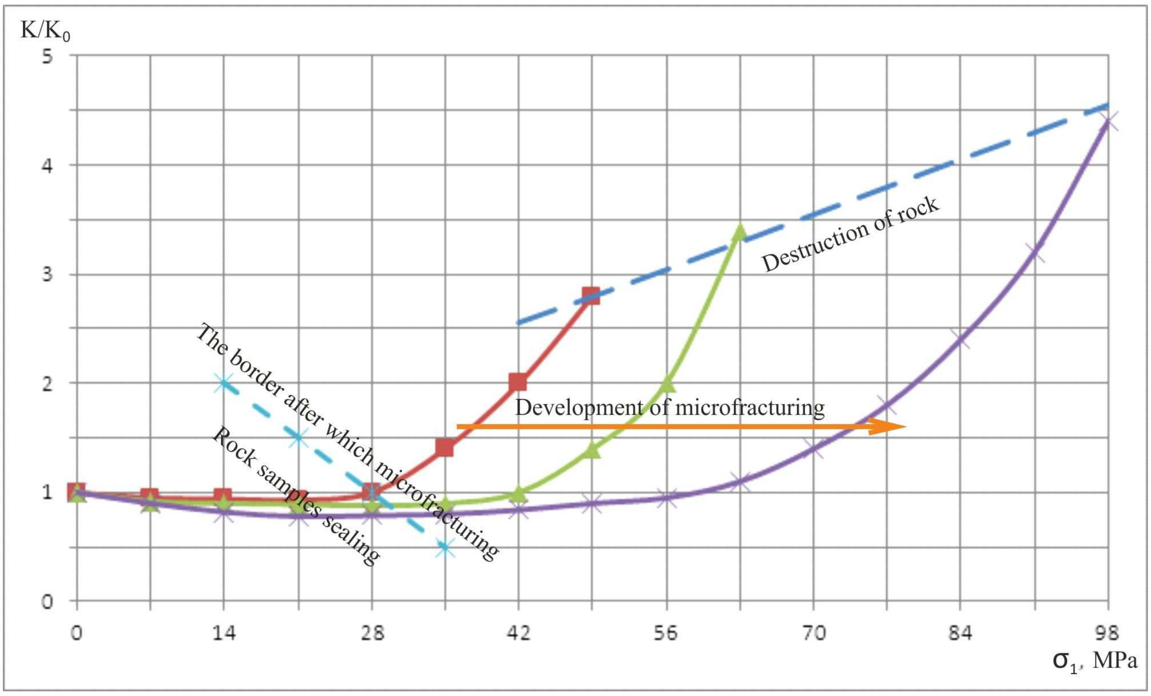


Figure 3 – Impact of hard-pressed / $\sigma_1 > (\sigma_2 = \sigma_3)$ / state on the character of the pore space change in the rock – the rock is first densificated, and after reaching the corresponding load for this rock microfractures develop, due to which permeability increases and occurs until the load is not reach destructive (K_0 – permeability under normal conditions, K_i – permeability at the corresponding load)

corresponding changes in permeability (Fig. 3). The load boundary is clearly fixed on the permeability and stress curves. After this value exceeded the development of microfractures began. In our case, the magnitude of the critical stress does not exceed 20–25 % of the destructive.

Discussion

Thus, with increasing pore pressure, the fluid that saturates the rock reduces its strength. At the same time, deformation dissipation increases. It is associated with micro-fracturing, especially for abnormally high reservoir pressure. While the stresses that provide such a process, according to our research, are much less than the strength parameters of the same composition rock with no fluid inside.

For reservoir formation in dense rocks, sufficient fluid and appropriate pressure are required. These conditions are possible in layered rocks with alternating dense and clay layers. With increasing pressure, clay rocks are suppliers of water, which in dense layers reduces their strength and consolidation. Under such conditions the corresponding power level of the layers for the given depth should be kept. Any deviations can lead the system out of balance. Then the process of changing the capacitive filtration properties can take place in the direction of consolidation reducing or its increasing. Thus, the thin-layered nature of the deposits section is an important prerequisite for the formation of a useful capacity in weak areas along the boundaries of different lithotypes, which leads to the layered fracturing formation. Menilite deposits are most characteristic for such section. Productive strata are represented mainly by the interbedding of thin cemented sandstones, argillites or other impermeable layers. These layers are composed of sandy and argillite seams, where it is impossible to talk of uniformity, isotropy of the granular pore system or its presence as such. Improvement of capacitive properties is related to the geodynamic processes of the Carpathian region development. As a result, different deposits can be reservoirs under the appropriate conditions for their development and occurrence, regardless of their lithological characteristics. It was also discovered that in wells where Eocene rocks are exploited, water content is growing faster than in wells that develop deposits of oligocene deposits. In further research it is necessary to establish the causes of the revealed signs. The first feature is described in the above-mentioned materials, where the second feature is partially characterized. The productive Eocene deposits layer is represented by the interbeddings of fine and coarse-grained materials alternating with interlayers of different thickness and permeability. Thus, on the boundaries of different facies, in particular, more and less sandy, zones of sub-vertical fracture are formed due to different sands and clays densification. These zones can contribute to the vertical flow of fluids within the one-aged deposits, and to combine them with the lower ones. The result is a complex fracturing system. This system consists of sub-vertical channels at the boundary of the facies and subhorizontal at the lithological boundaries. In the absence of a developed network of fractures, such stratum is almost unsuitable for further exploration. And the presence of fractures promotes the development of rocks with good reservoir properties. The flow in such a rock can be parallel to the layering and perpendicular to it. The deposit in such a situation acquires the properties of the porous reservoir, because the fractures network in the stratum has a random character. This means that the fractures are not oriented in one direction and do not have direct connection with the water-oil contact.

The productive seam of the Eocene deposits contains several deposits. Thus, in the Eocene deposits of the Dolyna field Vygoda and Maniava deposits are isolated and developed by different wells. The existence of the relationship between the Vygoda and Maniava deposits is given on the basis of the geological structure and the actual materials for the development of deposits. The correspondence of the initial pressure of the Maniava and the current reservoir pressure of the Vygoda deposits is due to the extraction of oil from the wells drilled for the Vygoda deposit.

The hydrodynamic association between the Vygoda and Bystrytsa deposits and the presence of interplayer flows between them indicate the data of testing and research of wells 234, 250, 625, 229, 300, and others. These wells exploit the Bystrytsa deposits. Despite the fact that all wells are situated in the crest of the deposit where there is no pressure of reservoir water, the water content of the extracted products is 10–17 %. Initial reservoir pressures corresponded to the current reservoir pressures of the Vygoda deposit, and the gas factor was in the range of 150–180 m^3/t. This corresponded to the amount of dissolved gas at the current reservoir pressure. Similar gas factors were also obtained on adjacent wells of the Vygoda deposit.

The actual data confirm the hydrodynamic association between the deposits, despite the presence of clay sublayers that do not affect the formation characteristic of the as a whole. Consequently, the reservoirs have a direct connection with the water-oil contact through fractures.

In theory, the dynamics of water production should be considered depending on the amount of oil selected from the original geological reserves. However, due to a certain convention of the received reserves and the complexity of obtaining such materials and keeping them in mind, it is problematic to use them in the analysis. The magnitude of the current water production and its change over the entire period of operation depend on many factors that operate at one time, therefore, it is difficult to assess the impact of each of them on the dynamics of water production. Most researchers attributed the nature and rate of water product to the structure and properties of the productive strata (lithological composition of the beds, their number, capacity, the presence of layers with reduced reservoir parameters (sometimes impermeable), structural and geometric parameters of the field or the deposit, the presence and nature of the transition zone).

Secondary porosity (fractures, cavities) has low values compared to the value of primary porosity. As a result, secondary porosity practically does not affect the amount of saturated hydrocarbon strata. In any case, it can be assumed that the fracture is 100 % saturated with the appropriate fluids: water in the water zone, oil in the oil, etc. Thus, in the direction of motion, the extrusion agent tends to move in fractures at a higher speed than in the direction of matrix blocks, which causes a high heterogeneity in the saturation of the fluids. On the other hand, the continuous penetration of the squeezing fluid from the fracture to the blocks results in a speed difference decreasing of the extrusion agent movement in fractures as well as in porous blocks. Fractures provide the transfer of hydrocarbons from the matrix to the wells. The pressure drop around the extraction well (the depression) in the fractured reservoirs is very small, that is why the high permeability of the fractures allows getting high debits at minor depressions. For the flow of oil through fractures small pressure gradients are sufficient, but they are so small that they are not able to control the processes of exchange of liquids between the matrix and fractures.

Conclusion

The main mechanism for extracting oil from reservoirs is capillary soaking. Due to the large difference between matrix permeability and fractures, water first enters the fracture, and then it is absorbed by the matrix. In fractured reservoirs, the matrix blocks can exchange liquids only through fractures that are adjacent to them. Consequently, due to the fact that the productive layers in the Menilite deposits are directly linked by fractures, and in the Eocene deposits, the same connection exists, then there is always the probability of a breakthrough of water through fractures and this process is difficult to predict.

References

[1] Mayevskiy, BY, Zderka, TV, Kurovets, SS & Yarema, AV 2010, 'Lithogenetic fracturing of Oligocene reservoir-rocks of the pre-Carpathian depression', *Journal of Hydrocarbons Mines and Environmental Research*, no. 16, pp. 53–59.

[2] Mayevskiy, BY & Kurovets, SS 2016, 'Hydrocarbons genesis and formation of their deposits as a basis of predicting oil-and-gas presence in deep-sunk horizons of sedimentary basins', *Eastern European Research Journal*, no. 4(8), pp. 140–158.

[3] Mayevskiy, BY & Kurovets, SS 2007, 'Mathematical model of fracture estimation of rock-collectors under conditions of their bending and its practical application (on the example of the Menilite deposits of the Carpathian Trench)', *Theoretical and practical aspects of geoinformatics*, Kyiv, pp. 137–148. [in Ukrainian]

УДК 553.981/982

Дослідження тріщинуватості порід-колекторів

***С.С. Куровець*[1]*, І.В. Артим*[1]*, І.М. Куровець*[2]**

[1]*Івано-Франківський національний технічний університет нафти і газу;*
вул. Карпатська, 15, м. Івано-Франківськ, 76019, Україна

[2]*Інститут геології і геохімії горючих копалин НАН України;*
вул. Наукова, 3-а, м. Львів, 79060, Україна

Наведено результати досліджень впливу фізичних процесів на колекторські властивості гірських порід. На циліндричних зразках керна з центральним отвором вивчено вплив радіального напрямку фільтраційного потоку на проникність. Оцінено вплив напруженого стану на проникність та тріщинуватість гірських порід.

Ключові слова: *порода, руйнування, серцевина, тиск, товща.*