Research technique and test experiments for the analysis of petrophysical properties of weak-consolidated and friable rocks

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Features of the development of unconventional gas

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International Conference "Reliability and efficiency of gas transport systems"

From 11 till 16 March 2013 in Yaremcha Ivano-Frankivsk region hosted an international conference "Reliability and efficiency gas transport systems."

The opening remarks and welcome speech for participants made S. Vynokurov - Chairman of the Board of JSC "Ukr-Transgas." At the international conference took place representatives of leading national and international oil and gas companies. Representatives of the national joint-stock company "Naftogaz of Ukraine" S.O. Storchak and V.O. Zaets prepared and presented a report entitled: "The main activities of the Department of labor protection, industrial safety and reliability of transporting oil and gas of the National Joint Stock Company "Naftogaz of Ukraine ". There is provided a presentation of the Company’s activities in the direction of transmission and underground storage of gas caused a wide interested of representatives of foreign companies as JSC "Moldovagas", OAO "Gazprom", LLC " Gazprom VNIIGAZ », NET4GAS, Eustream a.s. and others.

A well-grounded report of the engineer in-chief PJSC "Ukrtransgas" I.V.Lohman about the strategy on Ukrainian oil and gas sector modernization to improve efficiency and reliability of operation allowed to define the main priorities in securing further work effectively with an unique integrated transport and underground storage of gas.

Reports of Czech and Slovak partners about the asset management and the impact of "Nord Stream" construction on the operation of oil and gas sector in Slovakia, committed a special consideration of specialists.

International Conference held at the high level of proficiency and motivated professionals of worldwide companies to exchange ideas and the experience of work.

As recognized by international participants of the conference, close cooperation between the oil and gas community around the world not only fosters partnerships with gas transport companies in Europe, but also provides reliability of gas supply and a positive image of Ukraine abroad.
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Research technique and test experiments for the analysis of petrophysical properties of weak-consolidated and friable rocks

With the use of created measuring system for the study of petrophysical properties of incompetent, friable and loose rocks and sludge samples test experiments were performed on pit sand samples of known grain-size distribution, consolidated and disintegrated rock samples of Subbotin oil field of the Maykop formation. It was experimentally established that the shrinkage rate of soft rocks decreases sharply and attenuates at the effective pressure of 30 to 35MPa, which leads to stabilization of their filtration-capacitive and deformation behavior. The research of rocks, which are returned during drilling in the form of sand and cuttings, opens opportunities for using the obtained data for interpretation of production well logging and calculation of hydrocarbon reserves.

Practical experience in research weak-consolidated and friable rocks [1-5] indicates that it is generally impossible to get more information on their filtration-capacitive and electrical properties, since such collectors are destroyed during drilling and brought to the surface as mud or sand.

Preliminary analysis of laboratory studies, carried by V.M. Bortnytskyj, T.S. Izotov and Yu. S. Hubanov for fragile sand and silt rocks of the Middle Mykope deposits in South OGF shows that the decrease of porosity in sandstone unit at full load depends on clay content. At the range from 6.3 to 43.2% its compaction coefficient varies from 1 to 1.76. [1] Of course, such studies is necessary to fulfill with application of appropriate equipment and devices that constructive differ from those used to study consolidated collector rocks.

The aim of the Article is the development of research methodology and the creation of multifunctional, simple and reliable installation by which alternately on the same sample can be studied filtration-capacitive, deformation and electrical properties of weak-cemented and friable rocks of oil and gas.

Plant (Fig. 1) contains a sample holder 1, in which case pressed a Teflon bushing 2, all of which placed inside the weak-consolidated or friable sample or disintegrated sludge sample 3. Top and bottom of the sample (pattern) set perforate metal washers with radial grooves and rings of filter paper 4 rods 5 and 6, the perimeter of which is inserted rubber sealing ring 7. The lower 5 and upper 6 rods have central and side vents for filing the sample and withdrawal of working agent (gas, reservoir fluids, hexane), supporting that the closing valve can overlap the central rod holes 8, 9..
Lower rod 5 is set on plunger 10, which moves vertically in a supporting cylinder 11. Supporting cylinder 11 together with these components of sample holder 1 through pins 12, sleeve nuts 13 and 14 and the lid 15 is rigidly secured to the base 16. In the center hole of the upper rod 6 connected in capillary (with movable crane)6.

To plunger 10 and the upper rod 6 connected unit of measurement of electrical resistance 19. To the side hole of the supporting cylinder 11 through hydraulic line with gauge 20 is connected a hydraulic unit 21. The latter consists of a hand-press 22, filtration units (such УИПК-1М), which has a plunger pump with electric drive 23 and an additional set accumulator 24 (reduces pulsation pressure), made in form of thick-walled metal cylinder. It is possible to connect through the manifold 25 a vacuum pump 26 opening to the side hole of bottom of the rod 5. In addition, to side holes of the upper rod 6 through manifold 36 connected a node 27, containing a gas cartridge 28 (nitrogen) with reducer, drying tube 29 gauges 30, 34, manifold 31, a separator piston 32 filled with mineralized water or its model, crude oil or hexane through the valve 33. In the principal diagram of tester is the opportunity to connect to the manifold device 31 for measurement of open porosity of rocks by the gas volumetric method [6].

On the developed equipment conducted test experiments: evaluation of the possible error during the study due to shrinkage joints from different materials in sample holder (calibration curve 1 in Fig. 2) change in length (Δ L) disintegrated sample (pattern) during the steplike vertical loading (curve 2 in Fig.2) and the change in absolute penetration in course of above mentioned load (curve 3).
Even the first test laboratory experiments have shown that the tester is able to work at loads which exceeds 3000 kg/cm$^2 \cdot$ cm$^2$, which corresponds to an effective pressure of over 40 MPa and completely covers the depth interval, on which can occur friable and loose rocks.

For the experiments were selected two samples of pit sand (Lviv) and samples of friable clay sands from the well of 2-nd Subbotinskyi oil field destroyed in the process of reservoir water filling with total mineralization of 30 g/l. On each of the samples studied changes of its length ($L/L$) and the initial and current values of filtration-capacitive specifications in the process of the vertical loading growth that simulates the compaction of these rocks under effective pressure. In addition, with the help of continuous recording of loading and changing the length of the samples was determined a deformation modulus ($E_{st}$), i.e. Young's modulus in the vertical compression [4].

Preparing pit sand to research, it was sieved, dried and a sample of sand was weighed, in the sleeve 2 it was formed a cylindrical pattern with diameter and length of 30 mm. Core samples from the well of 2-nd Subbotinskyi oil field were dried, after that they destroyed in the stamp to the consistency of sand, in the sleeve they were formed in a cylindrical sample of size-defined.

The relative decrease in the length of the sample during researching from the well of 2-nd Subbotinskyi oil field the loading occurred steplike, without any violent changes. Since the vertical pressure of 250-300 kg/cm$^2$ (24.5 - 29.4 MPa) rate of shrinkage (contraction) of samples is decreasing (see Fig. 2). At each grade of samples load distribution was calculated a current porosity rocks, while its start value was measured by gas volumetric method [6]. The change of porosity during the research corresponds to the ratio:

$$K_s \cdot \frac{L_{\text{or}}}{{L}_{\text{or}}} = K_s^{\text{lt}},$$
where \( K_{II} \) – start porosity value, \%; \( L_0 \) – start sample length, cm; \( L_{pot} \) – current sample length, cm.

The correctness of this correlation was confirmed during the research of disintegrated samples (cylinders) from the well of 2-nd Subbotinskyi oil field, when during the loading, similar to the depths of their occurrence, the cylinder formed in the unit had similar to that, which was cut from the core of the cylinder. Thus, if a cylinder (sample 19.1) had a primary porosity of 22.9 % and at cylinder (sample 19.11) did not exceed 19.95 %, after compression of disintegrated samples up to 300 kg/cm² (29.4 MPa) porosity was respectively equal to 22.76 and 19.97 %. The match of the matrix - opened porosity and samples porosity (cylinders) formed into the tester, is very high, but it is possible that this accuracy may decrease with increasing research amounts and accuracy of the effective pressure.

Along with porosity was studied change in absolute gas permeability of the pit sand and simulation generated cylinders of sandy-clay rocks of the Subbotinskyi oil field. All disintegrated (bulk) samples characterized a high initial absolute gas permeability within \((298-553) \times 10^{-3} \text{ mkm}^2\). During the progressive loading it gradually decreased to 2 times or more. The maximum decrease in permeability occurred within the loads \((139-2119,5) \text{ kg/cm}^2\text{cm}^2\), whereas further on an absolute gas permeability decreases slightly. Thus, stabilization of the physical properties of weak-consolidated and friable rocks occurs at effective pressures of 30-35 MPa.

The calculations showed that the deformation module in friable rocks is much lower (samples 1 and 2) than in the disintegrated sandstone of the Subbotinskyi oil field containing a pelitic fraction of 12,9-21,9 %.

Thus, researches of friable rocks showed that using the above tester it is possible to conduct a variety of laboratory experiments to study the petrophysical characteristics of these rocks. This equipment also provides a possibility to make similar studies with consolidated reservoir rocks using standard sample holders.

References

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Analysis of the physical parameters of the sedimentary cover rocks of the northwestern part of DDD in connection with its oil and gas bearing capacity

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Density and volume magnetic susceptibility were studied from 8 boreholes drilled in north-western part of Dnipro-Donets Depression. The variations of these parameters were analyzed for the major rock types found in each of the wells. Magnetic susceptibility investigations of dry and fluid-saturated samples in heating process were pursued.

The forecasting oil bearing capacity problems of crust requires consideration of a wide range of processes and phenomena that somehow can be related to various aspects of the origin, migration and accumulation of hydrocarbons. One of the promising regions in this regard is the north-west part of the Dnieper-Donets basin. Oil and gas deposits are associated with Paleozoic sedimentary rock deposits, and probably of Precambrian basement formations. Here are drilled parametric and search wells: 333- Stroyivska (depth - 3803 m), 15- Borkowska (4776 m), 338- Nijinska (5337 m), 370- Zorkivska (6200 m), 303- Borznyanska (4508 m), 305 - Huzhivska (5501 m), 361-Savynkivska (6005 m) and 1 Petrivska (5501 m) from which was received important information about the composition and structure of the sedimentary cover and its relationship with the structures of the foundation. Magnetic susceptibility and density of rocks are the important parameters are very sensitive to the composition and structure of the geological section as well as the processes occurring in the earth's crust as a whole and in the sedimentary cover. These parameters are used to study the conditions of sedimentation, magnetostratigraphic separation of the sedimentary cover, as well as ways to predict migration and accumulation of hydrocarbons [1-4, etc.].

Laboratory studies of magnetic susceptibility and density of rocks are held on the same core material which is undoubtedly is very important for further explanation of anomalies in the density separation and magnetization of rocks and determine their relationships.

In general, the crust section of the study area represented by mudstones, siltstones, sandstones, limestones, marls, tuffaceous sandstones, tuffaceous argillites, dolomites, salt, tuff breccia, gneisses, basalts and gneissose granite. Gneiss and gneissose granite present the Precambrian basement. Measurement of density and magnetic susceptibility of rocks made for about 900 samples from all wells.

Research results

Magnetic susceptibility and density of samples are measured by standard technology. In result has been made density distribution and magnetic susceptibility rocks diagrams with depth of each well [5, 6]. Fig. 1 shows an example of the distribution of these values for the section of Borkowska well.

According to measurements, density and magnetic susceptibility of similar rocks vary in wide
limits. Except density of salt and basalt, which varying in minor limits, the density of other types of rocks covered in a wide range of values. In some wells are samples with anomalous density values: in particular for mudstones from Huzhivska well\(\sigma = 1.78\ \text{g/cm}^3\) (3564 m), siltstones of Petrivska well\(\sigma = 3.36\ \text{g/cm}^3\) (2793 m) and\(\sigma = 3.19\ \text{g/cm}^3\) (2783 m), limestone Nizhyn well\(\sigma = 3.01\ \text{g/cm}^3\) (2992 m). Note here, that siltstone samples of Petrivska well with anomalous density are characterized also by high value of magnetic susceptibility. Perhaps this can be explained by high content of magnetite, which is the main magnetic mineral of modern natural sands [7].

Also for samples of Borkowska, Borznyanska and Savinkivska wells was measured remaining magnetization. Its value is very small (0.003-0.1 A/m) for almost all samples, except nodules of Savynkivska well with \(I_H = 1.1\ \text{A/m}\) and magnetic sandstone of Borkowska well with \(I_H = 0.3-3.7\ \text{A/m}\).

To find some common samples of spatial variation in the density and magnetic susceptibility of rocks was made the construction of complex crust section from 1400 to 6400 m in all wells to mudstones, but siltstones, sandstones and limestones.

Fig. 1. Density and magnetic susceptibility of rocks of the Borkowska well

First of all we note that the density and magnetic susceptibility of rocks vary widely, but unless consideration of sandstone and limestone of Borkowska well and innumerable dense and magnetic rock samples from other wells, it is possible to identify such patterns.

The density of most of the mudstone samples varies from \(\sigma = (2.45\pm2.7)\ \text{g/cm}^3\), and magnetic susceptibility is \(\chi = (8\pm120)\cdot10^{-5}\ \text{CI units}\). The value of \(\sigma\) slightly increased, while the density increases sharply to the depth of 4500 m and from 5000 m decreases (Fig. 2). The density and
The magnetic susceptibility of most sandstone samples are \( \sigma = (2.3\pm2.7) \text{g/cm}^3 \) and \( \chi = (8\pm100)\cdot10^{-5} \text{ CI units} \). Both parameters are characterized with slight increase with depth. Such dependence is observed in the siltstone and limestone. A large number of samples siltstone has a density of \( \sigma = (2.4\pm2.72) \text{ g/cm}^3 \) and magnetic susceptibility \( \chi = (12\pm120)\cdot10^{-5} \text{ CI units} \). The density of limestone is within \( \sigma = (2.5\pm2.75) \text{ g/cm}^3, \chi = (5\pm50)\cdot10^{-5} \text{ CI units} \).

**Changing of the magnetic susceptibility of rocks under the influence of hydrocarbon and temperature.**

To identify possible genetic link between the magnetic susceptibility of different types of rocks and crowded places or passing hydrocarbons were studied changes for saturated and unsaturated rock samples under the influence of temperature for Stroyivska, Zorkivska, Borkowska and Nizhinska wells [6]. For the first time such an experiment has been carried out on the example of sedimentary and crystalline rocks of the Carpathian basin [4]. The result - the magnetic susceptibility of all types of rocks saturated with fluid, significantly increased and tumor magnetite was proved by X-ray analysis. A significant increase in the magnetic susceptibility of sediment experimentally determined for sedimentary rock formations of the Central Depression DDA[2].

Analysis of the results for the studied wells showed that not all rocks revealed the formation of new magnetic minerals, which exert itself in increasing of magnetic susceptibility of rocks saturated by hydrocarbon, i.e through the recovery process. Rocks of newly formed minerals after heating up to 350°C are mudstones, siltstones, marl, tuff breccia, sandstone. However, for a number of saturated hydrocarbon samples were observed abnormal growth of the values \( \chi \) and in some cases they even decreased.

A significant increase in the magnetic susceptibility observed for mudstones from the Borkowska wells with depth of 2250,8-2260,7m where the value \( \chi \) of sample saturated with gasoline, are significantly higher than the corresponding values of pure sample (Fig. 3). The same can be said about siltstone with depth of 3348,7-3355m, but in this case \( \chi \) of saturated sample is growing much more than unsaturated.

In Nizhyn borehole formation of new minerals with increasing temperature is observed in mudstones from the depths of 2620-2626m, where the saturated magnetic susceptibility of the sample increases in 5 times at 350°C, (\( \chi \) of unsaturated sample - only in 2.3 times), and mudstone from the depths of 3288-3295m, where \( \chi \) of saturated sample increases more than in 32 times. The same can be said of sandstone from a depth of 2986-2993m, where \( \chi \) of saturated sample increases more than in 13 times.

![Fig. 3. Diagramm of the magnetic susceptibility of the mudstone sample temperature from the Borkowska well](attachment:image.png)
In Zorkivska borehole formation of new minerals with increasing temperature occurs in clay (increase of $\chi$ saturated sample in 3 times) in sandstone (in 1.22 times) in siltstone (magnetic susceptibility of saturated sample is increased in 14 and unsaturated in - 9 times).
In all other samples investigated in family values increase $\chi$ saturated sample is almost there (as in gneisses Stroyivska wells) or increases less intensively than unsaturated. Very weak magnetic susceptibility changes siltstones and mudstones from the Borkowska wells during heating anomalies can be explained most the high values of $\chi$ before the experiment $\chi = 11450 \cdot 10^{-5}$ m. CI siltstones with depth in 2832m).

In general, we can note the different nature of the changes of magnetic susceptibility of saturated rock samples under the influence of temperature, and the presence of very-governmental them were of no newly formed magnetic minerals. Most likely derived samples can be explained by the lack of iron in some rocks in some form that is able to recover magnetite, or that the process of reduction of irons for some the reasons already passed.

Thus, the enrichment of magnetic and dense minerals may be associated with magmatic and volcanic activities, which are widely developed in the region, as well as possible by the interaction of rocks with fluids [2, 4].

Conducted investigations affords grounds for some conclusions, namely:

- increased density volume and magnetic susceptibility of many samples from the Borkowska well, and some rocks from other wells can be explained by saturation of iron containing minerals such as magnetite;

- experimentally demonstrated the possibility of magnetic minerals innovation in the event of temperature with saturated hydrocarbon fluid rock that found a genetic link of areas with high magnetic values with the ways of migration and accumulation of hydrocarbons;

An important feature is the identification in specific wells of intervals with decompaction of rocks, accompanied by elevated values of magnetic susceptibility. These intervals are allocated at different depths in Borznyanska, Nizhynska, Zorkivska, Petrivska, and Huzhivska and Savykivska wells. According to operations [1, 8], the following areas may be potential oil and gas bearing:

- great interest has a detection of mudstone decompaction area deeper than 5,000 m, near the crystalline basement, with increasing of their magnetic susceptibility, which creates prerequisites for predicting and finding this deep origin of hydrocarbons.

References

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Oil and gas bearing capacity of Paleocene carbonate formations of the southern oil and gas bearing region

According to the results of exploration work the industrial gas content of Palaeocene formation in the southern oil and gas bearing region is found within the western regions of plain Crimea and the northwest shelf of the Black Sea. Favorable conditions for non-anticlinal traps were also found associated primarily with cutting-in of collectors. 64.5 million toe in the off-shore and 21.5 million toe of hydrocarbons on land remain unexplored.


For today the territory of the North Crimea and adjacent areas of the Black Sea are covered by different types of geophysical surveys of unequal degree of detail and accuracy. Paleocene carbonate formation was studied by seismic works through the wave reflection method (WRM ), mostly in the first phase of oil and gas prospecting works (up to 1964 ). At this time also studied the general features of their structure, found and prepared for drilling local rising of shallow ground carbonate sediments of the Paleocene formation. Their structural plan clearly characterized by horizont reflection IIIa , dedicated to cover the carbonate strata of early Paleocene formation.

Within the water area Paleocene carbonate sediments that lie at depths of up to 3 km, mostly studied through seismic works WRM, and then more complicated modification of the method of wave reflection - a common depth point (WRM - CDP) in the first stage of geological and geophysical studies of marine areas to Ukraine early 70th centuries. Specifying the general features of the geological structure in comparison with the adjacent land of the North Crimea, where they were widely drilled. It showed local risings and prepare for exploratory drilling.

All within Crimea were conducted drilling operations on Paleocene horizons of 22 structures. In addition, these formations were studied in 69 areas where deep wells were drilled on Upper and Lower Cretaceous deposits. It was open seven gas and condensate fields. Success factor is 0,32.

In the Northern Black Sea Paleocene carbonate rocks were studied using wells that are drilled on Lower Cretaceous deposits.
In the north-western shelf of the Black Sea prospecting works in Palaeocene rocks were performed at six structures. In addition, such formation was studied in seven sites where wells drilled on Lower Cretaceous deposits. Drilled out Palaeocene deposit is 2.90 m/km². Six gas and gas-condensate fields were opened, three of which are in size of shown reserves belong to medium (Golitsyno, Odessa and Stormove).

Fig. 1. The initial hydrocarbon life of Palaeocene complex in Karkinitsky-Pivnichnokryi deflection within the Ukrainian sector of the northwestern shelf of the Black Sea as of 01.01.2012.

Fig. 2. The initial hydrocarbon life of Palaeocene complex in Karkinitsky-Pivnichnokryi deflection within the Ukrainian sector of the northwestern shelf of the Black Sea according to the elements of oil and gas geological zonation.

Fig. 3. The initial hydrocarbon life of Palaeocene complex in Karkinitsky-Pivnichnokryi deflection within the land as of 01.01.2012.

Fig. 4. The initial hydrocarbon life of Palaeocene complex within the land according to the elements of oil and gas geological zonation.

In general, at the study area and water area success coefficient is 0.46.

Among the 13 fields area with productive Paleocene-term horizons is one produced, which is used for gas storage (Hlibivske), two - under development (Golitsyno and Stormove).
Krasnopolyansk gas condensate accumulations is prepared for development, and Olenevsk is in operation and maintenance phase. Odessa, Bezimenne, Chernomorske, Karlavskе, Kirov, Zadornenske— are preserved. On two fields (Archangelske and Shmidtivske) an estimation of Paleocene gas bearing capacity is not actually completed.

Therefore it is defined the industrial gas content of Palaeocene formation within the northwest regions of plain Crimea and the northwest shelf of the Black Sea. It’s also found favorable conditions of non-anticline trap associated primarily with reservoir pinchout (Zahidnoholitsynsk area) [1–3].

The share of researched reserves of natural gas and condensate Palaeocene deposits is 65.4% (or 47,480 tons) of the total initial resources of the Crimean Black Sea oil and gas bearing area. Paleocene reserve has 170 thousand tons of Odessa Eocene deposit.

In general, in size of shown reserves Palaeocene formations are dominant among oil and gas complexes in southern Ukraine (more than 45% of their initial geological deposits in the region).

The initial hydrocarbon life of Palaeocene complex within the Ukrainian sector of the northwestern shelf of the Black Sea in Karkinitsky-Pivnichnokryi deflection as for 01.01.2012 are given in Table 1 and 2 and Fig. 1 and 2.

\[Table 1\]

The initial hydrocarbon life of Palaeocene complex within the Ukrainian sector of the northwestern shelf of the Black Sea in Karkinitsky-Pivnichnokryi deflection as for 01.01.2012

\[
\begin{array}{|c|c|c|}
\hline
\text{Hydrocarbon rank} & \text{General} & \text{harvested} \\
\hline
\text{Total mil tones} & 128,3 & 113,7 \\
\text{oil mil tones} & - & - \\
\text{condensate, mil tones} & 10,0 & 7,3 \\
\text{non-associated gas, bil m}^3 & 118,3 & 106,4 \\
\text{dissolved gas, bil m}^3 & - & - \\
\hline
\end{array}
\]

\[Table 2\]

The initial hydrocarbon life of Palaeocene complex of the northwestern shelf of the Black Sea according to the elements of oil and gas geological zonation

\[
\begin{array}{|c|c|c|}
\hline
\text{Elements of oil-gas geological zonation} & \text{Resourses, mil.tones} & \text{General} & \text{harvested} \\
\hline
\text{Crimean - Black Sea petroleum area} & 128,3 & 113,7 \\
\text{Tavriyska PR} & 11,8 & 10,0 \\
\text{Black Sea northern Crimea -oil and gas field} & 116,5 & 103,7 \\
\hline
\end{array}
\]

Table. 3 and 4 and Fig. 3 and 4 represents condition of the initial hydrocarbon life of Palaeocene complex in Karkinitsky-Pivnichnokryi deflection within the land.

\[Table 3\]

Initial hydrocarbon life of Palaeocene complex in Karkinitsky-Pivnichnokryi deflection within the land as for 01.01.2012

\[
\begin{array}{|c|c|}
\hline
\text{Hydrocarbon rank} & \text{Resourses} \\
\hline
\text{General} & \text{harvested} \\
\hline
\text{Total mil tones} & 27,5 & 24,2 \\
\hline
\end{array}
\]
Table 4
Initial hydrocarbon life of Palaeocene complex within the land according to the elements of oil and gas geological zonation

<table>
<thead>
<tr>
<th>Elements of oil-gas geological zonation</th>
<th>Resources, mil. tones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General</td>
</tr>
<tr>
<td>Crimean - Black Sea petroleum area</td>
<td>27,5</td>
</tr>
<tr>
<td>Tavriyska PR</td>
<td>20,8</td>
</tr>
<tr>
<td>Black Sea northern Crimea - oil and gas field</td>
<td>6,7</td>
</tr>
</tbody>
</table>

Thus, the degree of development of initial resources in the waters is 49.7%, i.e. there are still 64.5 million tones of undiscovered resources, on land thei degree of development reached up to 21.8%, there are 21.5 million tons of still undiscovered hydrocarbons.

Prospective areas on land is 21.45 km² on land - 1.04 km². The density of resources in the waters - 4.8 tons/km², on land - 2.2 tons/km². These data suggest the need to focus exploration of hydrocarbons Palaeocene complex primarily in the depths of the northwestern Black Sea shelf.

References
ANALYSIS OF VIBRATION EFFICIENCY OF DRILL STRING
USING THE THEORY OF RANDOM VIBRATIONS

Design features of the drill string and conditions of its operation give the opportunity to present it in form of suspended drilling line system on a mechanical system of connected in sequence by threaded sleeve elastic tubular rods.

To the drill string during deepening the well operate combined stresses of static and dynamic nature, which depend on the method of drilling, physical and mechanical conditions, drilling practices, etc.

Drilling equipment is set in rotary motion by motor through flexible drill pipe, so the action of external forces and moments will depend on the location of column in the well and on what forces act on it bottom, including: compressive - the axial load, bending - joint action of centrifugal force and gravity pipes twisting - from the moment of resistance to bit. Can not you-klyuchaty and hydraulic processes of drilling fluid.

Therefore, the drill string is a flexible system by which the process of drilling undergoing complex deformations caused variable in time and along the length of the column by combined stresses. Its length is much greater than the transverse dimensions. This elastic system takes tension, compression, bending, torsion and vibration corresponding processes which parameters can not be represented in the form of some known time function, as their value is constantly changing and is random (possible).

In the following we will take possible oscillatory processes as stationary and ergodic. Although in some cases such assumption is false due the fact that the statistical properties, such as geological, technical, identified during the observation of over one realization (in one area) for relatively long period of time, do not coincide with statistical properties obtained in the observation of many such recorded in other areas.

Tensionings arising from the drill string (destroying tension) depend on the technology of drilling and construction of the drill string. To determine the premature destruction associated with the appearing of the destroying tension, it is necessary to change them within acceptable limits, and to base a choice of layout and operational parameters on dynamic calculation.

In the following, for mathematical research of random random vibrations of the drill string in the process of deepening we will simulate it as the core with stepwise variation of cross section,
which is under the influence of axial and centrifugal force, torque, moved pressure drilling fluid.

The loads acting on the drill string during drilling, in generally, are not periodic in time. These changes can be described as a random process. To calculate the random vibration in order to determine the stress state of its elements can be used mathematical apparatus of the theory of random vibrations [1, 2].

Random vibration mainly caused by the interaction of the bit face, and hydrodynamic loads from the flow of drilling fluid. Random vibrations of the drill string that arise during the destruction of rocks with droves are transmitted to the bearing support in the form of kinematic perturbations vibrations. If occurs a wave-cut notch, then the teeth perturbation fluctuations is superimposed on harmonic oscillation component.

Farther, let us consider the vibration of the drill string during drilling under stationary random loads, including harmonized vibrations under wave-cut notch.

Structure of random stationary operation is characterized by significant perturbation functions at each moment of time \( u(t) \) and the degree of interconnection between the meaning in the moments \( t \) and \( t + \tau \). The specified degree of interconnection values \( u(t) \) and \( u(t + \tau) \) established by correlation function \( R(\tau) \), which is defined as the average time from extraction to \( u(t) \) and \( u(t + \tau) \)

\[
R(\tau) = \lim_{T \to \infty} \frac{1}{2T \tau} \int_{-\tau}^{\tau} u(t) u(t + \tau) dt;
\]

when \( T \to \infty \). (1)

Correlation function continuous stationary random process is pair correlation function of \( \tau \) with max. at \( \tau = 0 \). This maximum is equal to the average squared value of the random process

\[
R(0) = \bar{u}^2 = \lim_{T \to \infty} \frac{1}{2T} \int_{-\tau}^{\tau} u^2(t) dt;
\]

when \( T \to \infty \). (2)

where \( u \) – vertical movement of roller-cutter bit.

With increasing of \( \tau \) an interconnection degree \( u(t) \) and \( u(t + \tau) \) decreases, in consequence of which \( R(\tau) \) also decreases.

Therefore, the correlation function always has the form of decaying curve (Fig. 1). For a pure random process \( R(\tau) = 0 \).

Thus, upon availability of function \( u(t) \) periodic and constant axial load of components, based on equation (1) can be written:

\[
u(t) = u_0(t) + C_0 + C_1 \sin \omega t,\]

components are similar in function \( R(\tau) \):

\[
R(\tau) = R_0(\tau) + C_0^2 + \frac{C_1^2}{2} \cos \omega t.\] (4)

To calculate the correlation functions of the random process, its necessary to divide the diagram of specific implementation (Fig. 2) of random function \( u(t) \) for sufficiently large
Let us find the spectral density of a random process \( \Phi(\omega) \), which will enable to find out the reaction of the drill string at a random effect of any other power factors. The spectral density of random process is the Fourier transform of the correlation function

\[
\Phi(\omega) = \frac{1}{\pi} \int_0^\infty R(t)e^{-i\omega t}dt = \frac{2}{\pi} \int_0^\infty R(t) \cos \omega t dt.
\] (5)

The spectral density is a statistical characteristic of the energy distribution in the process of continuous frequency spectrum. This shows which share of energy contributes the system component to the total energy with frequency of \( \omega \).

Some sources [3] recommend to determine the spectral function using the Fourier transform directly the function \( u(t) \):

\[
\Phi(\omega) = \lim_{T_1 \to \infty} \frac{2}{T_1} \int_0^{T_1} u(t)e^{-i\omega t}dt \frac{1}{\pi} ;
\] (6)

Using for farther solution of the task propositions [4], we will consider the effect of moving the bit to work of drill string.

Rotation of roller-cutter bit results in reciprocating vertical moving, which passed to the column pipe.

In the drill string column occur elastic waves associated with migration of cutters from teeth to tooth and migration of cutters as cones over wavelike holioiw. Vibration energy partially intensify destroyment of holioiw, partially cover the column, leading to dynamic loads and its elements in further energy dissipation. According to [4], the longitudinal oscillations period of the bit in the case of synchronous rotation of the cutters is \( T_{\Pi.K} = \frac{60d}{znD} \), and in case of asynchronous rotation– \( T_{\Pi.K} = \frac{60d}{3znD} \). Oscillation frequency is \( f = \frac{1}{T_{\Pi.K}} \).

Movement of the lower end of the column due to movement of cutters over wavelike holioiw is equal to:

\[
h_y = A \sin \omega t,
\] (7)

where \( A \) and \( \omega \) – amplitude and angular frequency of longitudinal oscillations of the bit; \( \omega = \frac{\pi n}{30} k \); \( k \) – number of gable bottom, multiple to cutters.

The oscillation frequency is defined as \( f_1 = nk/60 \).
Another source of longitudinal oscillations is the rotation of the drill string. Because of the unevenness of rotation, specified with the heterogeneity of drilled rocks, changes in friction forces along the length of the column, the moment of resistance to chisel etc., is accidental changes of all oscillatory processes that occur and affect the overall dynamic condition of the drill string.

Fig. 2. The statistical data processing of vibrations on the top of drill string: $a$ – realization; $\tilde{\delta}$ – normalized spectral density; $\tilde{\sigma}$ – normalized autocorrelated function

Fig. 3. Amplitude-frequency response at the top of the drill string at the rotary method of drilling: bit CBГ-269, 3 diameter ОВТ 203 mm

It should be noted that a deterministic approach to solving the problem of determining the dynamic stresses in the elements of the drill string and reliability is approximate weighted character during the design of drilling wells is particularly complex profile requires the use of reliability theory and random vibrations [5].

In general, vibration and load acting on the drill string is space. These vibrations can be placed on the coordinate axes and viewed as a random function of only one argument - time. Therefore is investigated the stochastic process of the stochastic function of time. Analysis of vibration of the drill string on the base of the theory of random vibrations will help improve the reliability of the vibration of the drill string.

After analyzing the influence of random vibrations in the drill string, will divide them into a narrowband and broadband vibrations.

Broadband vibration inherent drill-circle under the rotary drilling method, when between a chisel and a column there are no structures with filtration properties, such as shock dampener, and vibration of the bit with almost no distortion come to ОВТ.

Narrowband drill string vibrations occur most often during stochastic broadband disturbances (friction, disturbance of drilling fluid pressure fluctuations), whose response to such perturbations is
narrowband stochastic vibration process.

For further analysis of drill string vibrations in the case of dynamic stochastic perturbations will use the results of work [6].

Narrowband vibration of drill string occurs as response to broadband disturbances. Mean frequency of narrowband vibration can be determined by formula Rice [7]:

$$\omega_0 = \frac{\int \omega \Phi_{rr}(\omega) d\omega}{\int \Phi_{rr}(\omega) d\omega} = \frac{R_r(0)}{R_r(\omega)}$$

where $\omega_0$ – frequency expectation; $\omega$ – trap frequency of process; $\Phi_{rr}(\omega)$ – spectral density of a stationary stochastic process.

![Fig. 4. Narrowband stochastic vibration process upper drill string during drilling by Turbodrill A7PD at Stryi deposit](image)

As shown in Fig. 1, the correlation function has the form of decaying curve, indicating a weakening correlation with increasing interval $\tau$.

$$R_{rr}(\tau) = R_0 e^{-\lambda \cos \omega_0 \tau},$$

To describe the correlation function in this case we can use the expression:

where $R_0$ i $\lambda$ – constant.

Spectral density is equal to:

$$\Phi_{rr}(\omega) = \frac{1}{\pi} \frac{AR_0}{(\omega - \theta)^2 + A^2} + \frac{1}{\pi} \frac{AR_0}{(\omega + \theta)^2 + A^2}$$

and its maximum, is close to the frequency $\omega = \pm \theta$. Resonance peaks in the amplitude-frequency characteristics (Fig. 3) is the process of white noise that proves: the expectation frequency $\omega_0$ coincides with the natural frequency of oscillation of the drill string in base tone. This may occur during drilling by turbodrill in solid and hard rock. The Fig. 4 shows the record vibrations on the top of the drill string during drilling by turbodrill A7PD in hard rock deposits in Stryi.

According to the expectation of frequency $\omega_0$ its possible to determine the envelope of narrowband vibration process of the drill string (Fig. 4):

$$A(t) = y^3(t) + \frac{y^3(t)}{\omega_0^2}.$$  

One-dimensional density complies with Rely distribution:
where $y_0$ – peak values of deformation of the column (including deflections) caused by normal vibration disturbance.

The response of the drill string to broadband stochastic vibration its possible to determine as the total perturbation of several narrowband stochastic vibrations. Then root-mean-square value of the drill string movement during vibration can be defined as:

$$
\sigma = \left[ \int_{f_1}^{f_2} \eta_f^2 \Phi(f) \, df \right]^{1/2},
$$

(13)

where $\eta_f$ – dynamic factor – the amplitude ratio of bits to relative displacement amplitude of logs at given frequency; $\Phi(f)$ – spectral density perturbations of stochastic vibration in the frequency band $f_1 \ldots f_2$.

If the broadband stochastic vibration operates on the drill string, then fluctuations are disturbing on all its own frequencies simultaneously, if the narrowband stochastic vibration with variable stochastic frequency operates on the drill string, resonant vibrations will be disturbed consistently.

As during the drill string vibration occurs a connection between the movement or a vibration speed and stresses as a criterion in the column and points of its interaction with wells elements, it is possible with equation (11) using the appropriate ratios to find the amplitudes distribution of the stress cycles under time of vibrations. In addition, we can calculate the distribution of stress amplitudes of cycles that are used to determine the possibility of damaging and fatigue.

In the case of stochastic disturbances of dynamical vibrations of the drill string similar to disturbing fluctuations in these systems, such as pipelines of power plants, constraint spectral density characteristics of the response and the disturbance can be written as

$$
\Phi_Y(\omega) = H(\omega)\Phi_{QQ}(\omega),
$$

(14)

density characteristics of the response and the disturbance can be written as

where $H(\omega)$ – transfer function of the drill string that binds disturbance and reaction and can be defined as the ratio of its response to harmonic disturbance to the value of the action; $\Phi_{QQ}(\omega)$ – spectral density of the dynamic load from the bottomhole.

Omitting the intermediate calculations and transformations, stress in the cross section of the drill string during stochastic fluctuations will be represented as

$$
\sigma_z = \frac{ED}{2} C_k(\omega) \frac{\partial^2 y_k(z)}{\partial z^2},
$$

(15)

where $E$ – modulus of elasticity; $D$ – outer diameter of the pipe; $C_k$ – expansion coefficient; $y_k(z)$ – characteristic function – column shape fluctuations; $z$ – longitudinal coordinate.
Forms voltage of \( k \)-shape fluctuations according to [6] can be written as:

\[
\sqrt{\sigma^2(z)} = \left[ C_c(\omega) \frac{\Phi_{\omega^2}(\omega)\omega}{\sqrt{(\omega^2 - \omega')^2 + (2\nu\omega)^2}} \right]^{1/2} \tag{16}
\]

The total stress in the drill string during stochastic fluctuations will be equal to:

\[
\overline{\sigma}^2(z) = \sum_{\omega} \sigma^2(z). \tag{17}
\]

It's possible to rate durability of the drill string during stochastic vibration using the definition of rms voltage according to (16), (17) and subsequent calculation of equivalent relative strength arising fatigue stress \( \sigma_p \) at pure harmonic load of the drill string.

Resistance to vibration is the longevity evaluation level assess of the drill string elements by first approximation. A more exact solution of the problem on the longevity evaluation elements of the drill string with due regard to metal fatigue requires the probability density determination \( p(\sigma)/T \) of the level overloading \( [\sigma] \) in a time of \( T \) median number of exceedence \( u(\sigma)/T \) in unit time median number of the exceedence \( u(\sigma)/T \) of the level \( [\sigma] \) at the time \( T \) [8]. Calculation of the listed characteristics should be based on an analysis of the real vibration statistics of the drill string during drilling for fixed area.

References


Authors of articles

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News
Natural gas dominates the infrastructure of pipelines

The planned volume of construction of gas pipelines in the world can lead to rapid growth in demand for natural gas. From the last review of «BP Statistical Energy Outlook to 2030", during 2011-2020 the consumption of natural gas in the world will increase annually by 2.5% compared to 0.9% increase in demand for oil.

Almost a third of the planned gas pipeline will be built in the Asia-Pacific region, which is characterized by rapid increase in demand for primary energy. This is due to the development of the economy, such as China and India.

Asia Pacific region is the largest consumer of oil and natural gas, which amounts to 2020 will be about 30.3% of global consumption. In 2011, the region consumed 26.5% of the total use of energy resources in the world.

WELL DRILLING
Application of clayless drilling fluids under conditions of high reservoir pressures and temperatures

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T.O.V. “Geosintezinzhenering”
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Boyko A.H.,
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PJSC «Ukrgazvydobutok»

The paper considers the application clayless drilling fluids under conditions of great depths, high reservoir pressures and temperatures. It was determined that increasing the density of clayless drilling fluids by conventional weighting agents is accompanied by increasing rate of bottomhole filtering. It is shown that the solution of this problem is possible through the use of water-soluble salts. The results of laboratory and field tests for clayless drilling fluids weighted with water-soluble salts are presented.

Recently, for the disclosure of productive horizons are increasingly used clayless rinsing fluids, which provide the highest level of conservation of reservoir properties [1, 2]. This largely is due to the low content of colloidal particle penetration of which to pore space of reservoir is a major factor in the deterioration of their productive characteristics. Moreover, if more recent clayless use was limited by areas of abnormally low or hydrostatic pressure, now it is increasingly may need to implement the deep wells with high reservoir pressure and temperature. However, the use of clayless weighted drilling fluid at high temperatures is confronted with a specific problem of uncontrolled growth of filtration rate, which is determined through a special device (tester HPHT or device GrozNDI) under conditions that simulate downhole filtering for reservoir temperature and pressure of 5 MPa (Fig. 1).

Our studies revealed a constant relationship between the content of the weighting as part clayless rinsing fluids and index of its packing filtration (Table 1).

Table 1

<table>
<thead>
<tr>
<th>Solution composition</th>
<th>Solution density, kg/m³</th>
<th>Solution filtration, cm³/30 min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>After preparation</td>
</tr>
<tr>
<td>Biokar</td>
<td>1030</td>
<td>2</td>
</tr>
<tr>
<td>Biokar +35 % baritu</td>
<td>1270</td>
<td>2</td>
</tr>
<tr>
<td>Biokar +70 % baritu</td>
<td>1480</td>
<td>2,5</td>
</tr>
<tr>
<td>Biokar +105 % baritu</td>
<td>1660</td>
<td>2,5</td>
</tr>
<tr>
<td>Biokar +140 % baritu</td>
<td>1820</td>
<td>2,5</td>
</tr>
</tbody>
</table>

Dependence of packing filtration of clayless solution on the content of the fine medium
It is found that, in the result of the introduction of relatively small amounts of barite (35% to volume), which corresponds to the density of 1270 kg/m³, packing filtration steps up to the limits of the technically acceptable values, and further increase of the density of rinsing fluid its packing filtration continues to grow and rapidly reaches immeasurable quantities in which filtered out almost all the volume of the liquid phase. Of course, such level of packing filtration makes impossible a performance of this type of rinsing fluid in these thermal conditions, since it leads to a deepening of volume filtration peel, which in the interval of bedding permeable can reach sizes capable of creating significant barriers boring tool movement (Fig 2).

It is revealingly that the ultra-high indexes of weighted clayless liquid filtration are almost no decrease with increasing of polysaccharide reagents concentration or with the introduction of additional heat-stabilizers. At the same time, after cooling of pre thermostating washing liquids to room temperature,

their low surface filtration is fully recovered. Thus, the increase in packing filtration of weighted clayless liquids are not associated with irreversible thermal degradation of reagents and of a different nature study which calls for specific research.

In our view, to understand the detected process is important to analyze the mechanism of rinsing fluid filtration.

It is known that the amount of liquid that is filtered under pressure through porous area for a certain period of time (a measure of filtration) is largely determined by the “density packaging material” filtration crust that forms on the surface of the area. When filtering mud in the formation of crust involved filtration of the solid phase particles of different sizes containing large amounts of colloid component. Under pressure from the crust is denser, so that its permeability decreases fairly
rapidly. Accordingly filtering mud tends to decrease over time and after reaching a certain value practically stops [3].

In systems of weighted clayless solutions, where the content of colloidal phase is very small compared with the concentration weighting, filtration crust formed mainly barite particles of approximately the same size.

This peel over time is almost sealed and resembles a cage or net, free space is filled with viscous polymer molecule. Under normal conditions of the experiment, corresponding to filtration on the surface, a polymer layer creates a durable and impermeable barrier that provides a low filtration rate cm³/30 2-3 min. However, at high temperatures, when the viscosity of the polymer decreases sharply, they lose their blocking properties. The frame of the particle barita becomes permeable, and filtering can reach 90-100 cm³/30 min and more. Cooled solution viscosity with increasing polymer recovers and low permeability cover filtration.

Thus, the reason for the increase of packing filtration of weighted liquids is an imbalance between the number of colloid and more coarse dispersed phase. This dependence was previously set for mud systems [4]. With decreasing value of the ratio between total and colloidal solid phases (including with increasing density of the solution, due to rising concentrations of weighting ) packing filtering of mud solutions increases sharply (Fig. 3). Accordingly, in the weighted clayless systems where the content of the colloidal component is much smaller, this effect should show up even more. Without solving this problem getting of clayless liquids with density over 1270-1300 kg/m³ for drilling at temperatures between 100 °C and above is out.

In our studies, the level of packing filtration of weighted clayless liquids could slightly reduce by entering their member colloidal barite, bentonite or chalk. But we could not completely solve the problem and achieve an acceptable level of packing filtering technology. In addition, the introduction of additional quantities of colloidal particles in clayless system deprives them of perhaps the most important advantages over the mud. Therefore, this line of research was recognized as false.

To increase the density of clayless rinsing fluid possible by processing with water-soluble salts. By this method of weighting its possible to violate the ratio between the colloidal and solid phases, and thus eliminate the key reason of the packing filtration multiplication.

Figure 2. Filtration cake of clayless solution which is not weighted (1) and weighted by barite up to the density of 1820 kg/m³ (2), after measuring at T = 140 °C and P = 5 MPa

Besides, the increase of the total environment salinity enhances the inhibitory properties of clayless system and thermal stability of biopolymer reagents [5]. The clayless washing mud weighted by water-soluble salts keeps all the positive characteristics of traditional biopolymer systems: low surface filtration, high level of pseudoplasticity, instant toxitropia, etc. (Table. 2).
### Table 2

Parameters of clayless solutions weighted by different water-soluble salts

<table>
<thead>
<tr>
<th>Solution composition</th>
<th>Density kg/m³</th>
<th>Relative viscosity 100/200 mPa.s</th>
<th>Фільтрація, cm²/30 min</th>
<th>ONZ, dPa</th>
<th>Plastic viscosity, MPa *c</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biokar</td>
<td>1030</td>
<td>26</td>
<td>16–18</td>
<td>18</td>
<td>19</td>
<td>24</td>
</tr>
<tr>
<td>Biokar + 27% NaCl</td>
<td>1220</td>
<td>23</td>
<td>2,5</td>
<td>17–19</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Biokar + 25% NaCl + 38% CaO₂</td>
<td>1340</td>
<td>25</td>
<td>2</td>
<td>18–20</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Biokar + 25% NaCl + 65% Ca(NO₃)₂</td>
<td>1480</td>
<td>30</td>
<td>3</td>
<td>16–20</td>
<td>38</td>
<td>44</td>
</tr>
</tbody>
</table>

### Table 3

Characteristics of washing mud ‘Biocar-MT’ during drilling of the well Svyridivska

<table>
<thead>
<tr>
<th>Density kg/m³</th>
<th>Relative viscosity, c</th>
<th>Standard conditions at T = 140 °C and P = 5</th>
<th>ONZ, dPa</th>
<th>Content of coloids, %</th>
<th>Total salt content, %</th>
<th>Content of KCl, %</th>
<th>Plastic viscosity, MPa *c</th>
<th>pH</th>
</tr>
</thead>
</table>

### Table 4

Characteristics of washing mud ‘Biocar-MT’ during drilling of the well Ostroverkhivska

<table>
<thead>
<tr>
<th>Density kg/m³</th>
<th>Relative viscosity, c</th>
<th>Filtration, cm²/30 min at T = 120 °C and P = 6</th>
<th>ONZ, dPa</th>
<th>Content of coloids, %</th>
<th>Total salt content, %</th>
<th>Content of KCl, %</th>
<th>Plastic viscosity, MPa *c</th>
<th>pH</th>
</tr>
</thead>
</table>

Depending on the type of salinity machine it is possible to have clayless washing mud with different density. Thus, in the case of sodium chloride the drilling mud density will be 1250 kg/m³, calcium chloride - 1380 kg/m³, calcium nitrate - about 1500 kg/m³. The use of relatively cheap salt allows having the drilling mud which density corresponds to formational pressure of most deposits of Ukraine. To obtain clayless liquids with higher density, you can use the more expensive salts - calcium bromide, zinc chloride, etc.

The industrial tests of developed drilling fluid "Biocar-MT" which is weighted by sodium chloride, held at Svyrydyske deposit at reservoir temperature of 136°C. The selected trial place results from unsuccessful experience of use of barite weighted clayless solution ‘Baradrill’ (developer – ‘Vahoisi’), so the performance of most drilled wells was lower than planned.

In our opinion, the main cause of the problem was underestimating the importance of high factor of packing filtration inherent to clayless liquids during their weighting by barite. Another reason was the increase of the density of the drilling fluid, which was explained by the low resistance of rocks and shattering during drilling. The solution weighting led to the creation of ultra-
high ranges of repression within dive horizons, which reached 15-20 MPa.

Uncovering of layers of high repression and packing filtration naturally leads to pollution and low flow rates because of the formation of large areas of penetration. The indirect confirmation of this conclusion: the flow rates of wells drilled in Soviet times using the old clay mud is significantly higher. This paradox can be explained by the fact that even the limited filtration by "bad" mud leads to less pollution of layers than the excessive packing filtration by "modern" weighted clayless liquids.

The washing mud "Biocar-MT" weighted by sodium chloride to the density of 1220-1240 kg/m3, was introduced during the drilling of the interval for the production string (4800-5450m) in well 53. The interval drilling was carried out with the speed for this deposit. Drifting was close to 50 meters per day, and the entire interval was drilled in less than a month.

The increase of mineralization of drilling mud ensured the high level of clay rock inhibition to keep its density at lower level than during the drilling at the deposit (1320-1360 kg/m3 and more). The rigidity of rock was high, caving was not observed. The parameters of washing mud were stable and almost unchangeable during drilling (Table 3).

The absence of weighting coarse particles in the solution made it possible to use effectively such cleaning means as hydrocyclone and centrifuge installations. Regardless the disclosure of strong clay roof of productive layers, the concentration of colloidal particles in solution was minimal. The absence of contaminating components allowed the efficient use of reagents-colmatants that had been introduced into solution immediately before the opening of the first productive facility. It ensured to provide high-quality disclosure of layers; and avoid possible differential tacking. During handling operations in the intervals of permeable layers the tool moved freely, indicating the absence of increase of filter cake and restriction zones.

The absence of contamination of productive reservoir during drilling in low layer pressure is proven by data of industrial and geophysical studies. In particular, the results of electrometric methods of GDS it was found the absence of zone of the filter agent penetration to the productive layer with porosity ratio of 11% within 5,194-5,200 m. During the test of wells we received the industrial flows of gas and condensate exceeding the flow rates of deposit adjacent wells.

Other example of successful use of clayless biopolymer liquids weighed by water-soluble salts is the well 62 of Ostroverkhivsky Deposit, where there was gas show during the opening of the reservoir depth at 4,368 m. The density of clayless liquid ‘Biocar-MT’ reduced from 1220 to 910 kg/m3 as resulted from gas. There were signs of intensive argillite caving accompanied by pressure fluctuations during washing and tools pulling. To overcome the complexity it needed to increase the density of the drilling fluid to 1,360 kg/m3. But downhole temperature was about 120°C, it prevented the use of traditional weighting system within the system of clayless drilling mud. There was used calcium chloride (Table 4).

Calcium chloride is traditional inhibitor of deconsolidation of clay rocks; it was widely used for drilling mud in 70-80s of the 20th century. But inhibiting properties of such solutions were restricted by rather low concentration of ion Ca2+ that was caused by problems with their stabilizatation by lingosulfonate agents. The polysaccharidic base of ‘Biocar’ ensures the stabilization of even saturated calcium chloride brine, and it ensures to increase considerably the inhibiting characteristics of the washing liquids on its basis.

The same situation is with other polyvalent salts, including magnesium chloride and calcium nitrate which show better results than calcium chloride (3-5%) due to their high concentrated brines with inhibiting effect for clay rocks (Fig. 4).
Figure 3. Dependence of filtration of VLR-stabilized drilling mud, on rate of clay colloid characteristics ($K$) [4]: 1/2-filtration in normal conditions of solutions with density 1.4 and 2.0 g/cm$^3$; 3-filtration at $T = 140 ^{\circ}C$ and $P = 5$ Mpa of unweighed solution; 4-7-filtration of solutions with density 1.4; 1.6; 1.8; 2.0 g/cm$^3$ respectively in similar conditions.
The increase of inhibiting properties of solution ‘Biocar MT’ because of insertion of calcium chloride simultaneously with increase of its density helped to eliminate the complications at well 62 and lower the casing well within a short period of time.

Thus, the use of water soluble salts ensures to exclude from clayless washing mud the standard weighting agents which increase the packing filtration and makes them unsuitable for use at high packing pressures and temperatures. A side effect of water-soluble salts weighting are to increase the thermal stability of biopolymer systems and growth of their inhibitory properties

The successful conduction of industrial tests of clayless biopolymer solutions weighted by water-soluble salts is a successful evidence of theory consideration on which a new concept of use of clayless solutions at deep water where the majority of effective objects of Ukraine are located.

References


NEWS

Gas Deposit was put in production in Israel

First cubic meters of natural gas were supplied to Israeli clients from the newly-found of offshore gas deposit ‘Tamar’. The deposit located in the Mediterranean Sea was found in 2009. After construction of the gas pipeline the gas was distributed to the terminal in the Ashdod Port.
According to the Ministry of Energy of this country the deposit will satisfy 50-80% of Israel needs in natural gas for at least 10 years. The half of Israeli power is generated with use of gas. The discovery of the second important offshore gas deposit in the area of the Northern Israel, known as Leviathan, can make Israel the gas exporter.

Pipeline & Gas Journal/ May/ www.pgjonline.com, p.18

New record high of drilling depth in Indian waters

‘Transocean Ltd and Oil&Natural Gas Corp.’ declares the new record high of offshore depth achieved by the well drilled in Eastern Part of Indian water surface.

From the driller ‘Dhirubhai Deepwater KG1’, the drilling of the extension well ‘ONGC NA7-1’ at the sea depth of 3,407 m was completed on January 23, 2013. The estimated well depth is 5,367m.

This company achieved the earlier record high – 9,727 m in the Eastern Part of the Indian water surface in 2011.

http://www.ogj.com/content/ogi/en/articles/2013/02/
WELL DRILLING

Sidetrack in well casing

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The analysis of the window milling was carried out. According to analytical studies were received mathematical formulas that allow determining the deflection on milling tool and dogleg severity of sidetracks in well casing. Recommendations to reduce the hole deviation angle in casing area are given.

The rational use of drilled hole is a key role in improving the fuel and energy balance of Ukraine. An important reserve for increasing the volumes of oil and gas is inactive, killed and liquidated wells which take a significant share in many deposits of Ukraine. Having analyzed the state of exploitation of main deposits, we can make a conclusion that a great number of obsolete wells may be and should be renewed and put in service to save expenses for new wells drilling.

Today, the technology of sidetrack through milling window in the well casing is the most popular one. The advantages of this technology are: time saving, less volume of metallic sludge, less possibility of accidents during the window milling in the well casing due to use of tools without movable and sliding elements [1-4]. In addition, it is possible to mill the window in the well casing of diameter of up to 168 mm at the depth exceeding 2000 m, as well as in wells which zenith angle is over 5°, and through several well casings [5]. The advantage of this technology is also in possibility of accomplishment of all the works of well reconstruction by rotor system without use of packing machine.

During kickoff and drilling of the additional well bore, the process of formation of hole-like window in well casing is the most important moment. In this case considerable curving forces appear in drill column and it is resulted in problematic passing of this section [6-8]. Some authors state the break of the drill column when it is in the window zone [9, 10]. Besides, there are eventual complications during lowering the well casing and fixation of additional bore. In this case some pressing forces appear because of deformation of pipes in the window, and it will be impossible to lower the well casing in additional bore or its diameter will be deformed [8, 11, 12]. The abovementioned complications and emergency situations are primarily explained by authors by large angle of wedge deflector and as a result small length of window in the well casing, but their evidences are not always justified.

So, we can say the process of window forming in well casing during drilling of additional bores is a complex one, and can be accompanied by accidents; however, there are no detailed studies in this area.

This article is aimed at highlighting the results of theoretical studies of the process of window milling in well casing during drilling of additional bore.

The window milling process in well casing starts when reamer contacts with the well casing, deepens in the wall of the well casing along the AB line till full entering outside limits (Fig. 1)

Then the reamer forms the window of some configuration which depends on geometrical parameters of well casing, reamer and wedge deflector. After completion of window milling, at the final stage, the ditch along CD line is formed; it is located along outer surface of well casing. Then the drilling process continues for several meters for entering the bore in the stable zone of rock near bore [13].
The fig. 1 schematically represents the construction of the conic reamer which is widely used in Russian Federation and other CIS countries during reconstruction of inactive wells by abovementioned method [7].

At the final stage of window forming in well casing (CD line) the reamer works in heterogeneous environment. On the one side it contacts the well casing and coupling, which mechanic characteristics are higher than rock and cement stone characteristics. It is obviously that in such situation the deflecting force influences the reamer from the well casing (coupling), which will cause its deflection from the straight-line trajectory towards the rocks. The length of contact of reamer with well casing depends on inclination of wedge deflector, depth of the well casing wall and coupling (in case of milling of well casing in the place of coupling location). The length of ditch in well casing (СБ line) may be 600-650 mm.
Considering the classical provisions of rock mechanics and operation of rock-destroying tools, we received the following formula for calculation of deflecting force acting from the well casing:

\[
F_{\text{in}} = \frac{F_{oc}}{\tan \alpha} \left( 1 - \frac{r^2}{R^2} \right) \left( 1 - \frac{E_M}{E_M} \right) \left( \frac{S_M}{S_M} + \frac{E_M}{E_M} \right)
\]

where \( F_{oc} \) – axial load on reamer; \( r, R \) – minimum and maximum radii of conic working surface of reamer; \( E_P, E_M \) – modules of rock elasticity and material of well casing; \( S_M, S_P \) – surfaces of parts of lateral surfaces of faces, formed from metal and rock; \( \alpha \) – inclination generating conic surface of reamer to its axle.

![Figure 2. Dependence of deflecting force at reamer on correlation of its radii r/R: 1, 2, 3 – axial load as per 10, 15 and 20 kN](image)

The equation (1) shows that the value of deflecting force \( F_{\text{in}} \) depends on constructive elements of reamer \( (r, R, \alpha) \), and from degree of environment heterogeneity \( (E_P, E_M, S_P, S_M) \).

In our case (see Fig. 1) reamer destroys metal of well casing and coupling, cement stone and rock. Modules of elasticity of cement stone and rocks of medium hardness are almost equal, and we consider that the reamer operates in environment rock-metal.
Due to the equation (1) we conducted a study to identify the degree of dependence of value $F_{\text{w1d}}$ on some constructive parameters of reamer and values of environment heterogeneity in case of change of their real values within defined ranges and constructed the appropriate dependencies. We studied the dependence of value $F_{\text{w1d}}$ on defined parameter(s) on the basis of the average values of others.

The Fig. 2 shows the dependence on the deflection force on reamer of its radii ratio $r/R$. The figure shows that at different axial load we obtained a number of lines of approximately the same angle of inclination to the absciss axis. Depending on value of axial lad and values $r/R$ of deflectign force can change within $1,9—5,7$ kN.

The fig. 3 shows the dependence of deflecting force on reamer on correlation of elasticity modules $E_{\text{r}}/E_{\text{m}}$. Graphic dependences have the form of monotone curves, reflecting a decrease deflecting force on reamer with the increase of the above mentioned correlation, as in this case the difference between the rock elasticity modules and metal decreases. On the basis of the mentioned
graphic dependencies the deflecting force on reamer can change within 1.9—6.2 kN.

The figure 4 shows the dependence of deflecting force in reamer on correlation of metal and rock surfaces SM/SII. The graphic dependencies are curves reflecting growth \( F_{m} \) with increase of correlation SM/SII. Such increase is logic, as the deflecting force increases with the growth of metal surface of well casing. Depending on value of axial load and values SM/SII the deflecting force may be within 1.5-6.6 kN.

If we know the value of deflecting force on reamer, we can define the intensity of crookedness of well bore as per the formula [14]:

\[
\frac{d\alpha}{ds} = \frac{2}{L} \left( \beta_0 + \Theta + K \frac{F_{m}}{F_{w}} \right)
\]

where \( L \) – length of directing section from reamer to contact point of loaded drilling pipes with well wall; \( \beta_0 \) – angle of misalignment of the bottom of the drill string; \( \Theta \) – turn of reamer axle under applied axial load; \( K \) – coefficient of milling characteristics of rock-destructing tool.

(1) As destructing characteristics of reamer in axial and transverse directions is equal, then \( K = 1 \). Considering (1) the formula (2) will be:

\[
\frac{d\alpha}{ds} = \frac{2}{L} \left( \beta_0 + \Theta + \sqrt{\frac{1 - r^2}{L^2}} \frac{S_m}{S_n} \frac{F_n}{F_m} \right)
\]

The formula elements \( L \) and \( \Theta \) may be found by solving the differential equation of curved axle in the bottom of well casing in inclined well.

The results of calculation of intensity during reamer operation in heterogeneous environment showed that in case of different correlations of parameters of reamer and environment the values may be within 5.7-18.1 grad/m. Considering the inclination of wedge deflector, the density of walls of well casing, as well as possibility of reamer contact with coupling, the general inclination of additional well bore may be within 1.7-8.2 grad. Thus, within the zone of reamer exit from well casing, there may be some local deflections which are probably have a negative influence on the operation of drill string bottom.

These considerable local deflections may negatively be reflected on operation of drilling string bottom.

The developed method of calculation of intensity of incline of drilling string ensures to evaluate properly its values, as well as define the ways of decrease. To reduce the inclination of bore during window milling in casing well, it is necessary to increase the inclination of wedge deflector to necessary value, use spherical or cylinder reamers, as well as conduct milling works between couplings of well casings.

We plan to conduct theoretical studies to evaluate the deformation state of the bottom of the drill string through the process of formation of slit-like window in well casing.

References


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**International Scientific Gas Conference**

*International Gas Union plans to hold the International Gas*
Union Research Conference (IGURC 2014) on September 17-19, 2014 in Copenhagen (Denmark).

The conference ‘Gas Innovations Inspiring Clean Energy’ will host
over three hundred reports at plenary and section sessions. The plenary sessions will discuss such issues as:

Influence of innovations on gas market;

Business conditions for scientific research works and industry development;

The most important factors for technologies change; and

Current news from the world of gas technologies.

The Agenda includes the issues of gas use, its transport and distribution, gas production,
environment protection, security, communications, markets, supply, strategies, etc.

The reports abstracts should be sent until January 6, 2014, participants’ registration starts on November 1, 2013;

See detailed information at web-site www.igrc2014.com
OIL AND GAS EXTRACTION

The main directions of the field development systems improvement and the potential of oil extraction increase in Ukraine

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The main reasons for reduction of oil and gas extraction in Ukraine are presented. The priority directions for improving the oil and gas field development systems and the potential increase of oil and gas extraction volumes in Ukraine are substantiated. The possibility of involvement of passive reserves of oil in active development and increase of the annual oil extraction by implementation of modern oil and gas technologies are forecasted.

The petroleum industry of Ukraine, like in the most oil-extracting countries, passed the period of the maximum amount of extraction, followed by the inevitable downturn. The maximum level of oil and condensate production (14.4 million tons, 1972) was ensured by commissioning of a number of large oil and gas fields located in Dnipropetrovsk and Donetsk basin. Their role remained unchanged, and now about 20% of deposits provide 80% of hydrocarbon extraction, and the remaining 80% - only 20% of extraction [1]. The attempts to reduce the rate of decline in production, which were made primarily by increasing the operating drilling area, as well as identification of the previously omitted intervals and segments, had an episodic character and for various reasons were not able to change the overall trend of the oil and condensate extraction curve for more or less considerable period (Fig. 1).

The key reason for decrease in oil production in Ukraine is a natural transfer of most fields major by production and stocks to the later stages of development, characterized by significant depletion after extraction of 80...85% of oil from the approved initial extraction reserves [2, 3]. On the other hand, the time of commissioning of large deposits ensuring the growth of stocks has expired and the geological exploration opens mostly very small, small and medium-sized deposits at the depths of 4.5...6 thousand meters. The developed reserve gains, therefore, do not compensate even the current oil production. The comparative analysis shows that the intensity of systems for exploration of oilfield in Ukraine, especially with large values of initial stocks, corresponds to the world standards achieved, and sometimes even exceeds the same, but small fields are developed much slower than usually in the world [3].

Over the past 15 years, the resource base of oil and gas complex of Ukraine has deteriorated significantly, its competitiveness in the introduction of modern petrochemical technologies has decreased, the volume of seismic studies and exploratory drilling and thus, the gain of hydrocarbon reserves have been reduced significantly. The share of hard-extraction hydrocarbons is growing in
the structure of hydrocarbon reserves [4]. For a 30-year period their number in Ukraine has nearly tripled and exceeded 68% of total reserves. The structure of the remaining oil reserves is deteriorated due to the fact that the selection of hydrocarbons is carried out mainly from the active parts stocks.

The exhaustion of deposits in Ukraine is accompanied by the increased water content of products up to 80...85% and more. Thus, 14 fields of the oil company UkrNafta JSC are developed with average water content greater than 90%. The mean extraction coefficient has reached about 30% of the designed value 36.5%, while the global level for the corresponding mode of development is 40-50%. For example, in neighboring Belarus the state oil and gas company Belorusneft PORUP has reached the oil extraction coefficients of 50-55% on the major development sites. Considering the current resource base of oil fields in Ukraine, which are being developed (Figure 2), we can note a significant proportion of the residual oil which substantially exceeds the current amount of extractable reserves. Actually, the residual stocks of deposits accounted for the public companies exceed 740 million tons.

Therefore the main focus of increase in the levels of hydrocarbon extraction and achievement of high values of the terminal coefficients of their extraction is a massive improvement of the existing oil and gas deposit development systems using the modern high technologies. Major oil fields of Ukraine are developed with the method of flooding, which is currently the most affordable and effective. Still, due to the complex geological structure, high filtration heterogeneity, separation and reservoir non-continuity, transfer of fields into the final stage of development, the effectiveness of flooding at this stage is low. The direct flow-metric studies show that deposit is cut by the pressurized water into separate blocks, plots (Fig. 3). This, in turn, leads to the formation of undiscovered, little permeable layers and non-drained zones, which, according to expert estimates [5], present about 46% share in the general distribution of residual oil (Fig. 4).

Based on the results of numerous studies it was established that about two-thirds of the residual oil occurs due to incomplete coverage of the reservoir by development, and its remains are kept in the pore space by capillary and surface forces.

The domestic and international experience [5, 6] suggests that the modern oil industry has a wide arsenal of technology for localization and removal of residual oil stocks. In Ukraine the efforts of many professionals for stabilization and increase of the levels of oil extraction have led to establishment of scientific principles to improve the existing oil and gas development methods, which are aimed at improvement of technical and economic efficiency of introduction of modern innovative technologies for extraction of hydrocarbons and an increase in hydrocarbon extraction in the environment of stock structure deterioration [7-9]. Firstly, they should include:

permanent stock-development monitoring system based on hydrodynamic modeling;
method of rapid assessment of the technological efficiency of oil and gas development systems and formation of the primary recommendations aimed at their improvement;
methodological basis of long-term forecasting of oil and gas extraction levels;
method of localization uncultivated areas of the reservoir and the optimal location of sealing wells;
technologies for enhancement of productivity of wells, limitation of reservoir water inflow,

elimination of overflows over the column etc.

Figure 2. Resource oil base in Ukraine

The modern instrumental controls over the development of fields and complete exhaustion of production stocks, the results of theoretical, experimental and industrial researches, advanced scientific methodological and software technical means of monitoring mining, evaluation of technical efficiency, construction of geological and technological models allow localizing the places of concentration of residual stocks with sufficient certainty and optimizing the systems and the location of wells.

Based on the methodology for long-term forecasting of oil extraction [10] and assuming that subject to systemized and programmed approach the investment and, consequently, the rate of the development of additional reserves can be compared with the results achieved during the exploration and development of new deposits in Ukraine. We performed the stock growth scenario forecast (Fig. 5) and oil extraction therefrom (Fig. 6). The pessimistic scenario corresponds to 90%, plausible - to 50%, and optimistic – to 10% confidence level. As you can see, even in the pessimistic scenario the implementation of modern technology to improve the existing system of oil field development will enable the involvement of about 80 million tons of oil in active extraction. It can provide the annual production growth over the next five years to 0.5 million tons, accounting for 12% of the current level of oil production in Ukraine. According to plausible scenario, these figures are even more optimistic, i.e. the additionally attracted stocks will amount to 120 million tons, an increase in annual production for the next five years will be 0.5...1 million tons, which is 12...25% of the current level of oil production in Ukraine.
So, it is economically and technologically justified to involve 100...150 mio tons of oil from the current residual stocks in development in the fields of Ukraine, which is equivalent to achieving the final factor of the oil extraction of 46...51%, which corresponds to the modern global development systems [11].

To ensure the implementation of these scenarios it is required to solve a number of urgent technological and organizational problems.
The first technological challenges are:
deployment of wide industrial and scientific researches for localization of residual oil;
introduction of modern methods of oil extraction;
optimization of the production wells grid;
boring of wells with complex architecture, including the multi-drilled with horizontal shaft;
high-quality primary and secondary exposure of productive layers;
application of flow-deflecting technologies directed methods of enhanced extraction and limitation of inflow of the formation waters etc.

In this area, the principles and technologies of the system targeted insulating and intensifying effect on the bottomhole zone, filter, borehole, reservoir and reservoir areas between wells have been developed:
methods and technologies of oil deposits development;
methods of formation water flow restriction and removal
of leaks in the space after the columns with various filterable and non-filterable plugging materials in the injection and production wells;
ways of intensification of oil production combining the mechanical, thermal and chemical actions in one technological action;
ways of identification of gaps in the flooded reservoir, modern approaches to reinterpretation of seismic study findings and geophysical wells researches;
methodology of development of permanent hydrodynamic models of hydrocarbon deposits.

Among the organizational tasks, it is important to develop the respective branch-specific and industrial applications, development and intensification of the system for state control and regulation of mining, provision of conditions for attracting investment and reduction of risks, especially the financial ones, for implementation of programs to improve the development the systems of oil fields development in Ukraine.

So, with the limited opportunities of opening new fields with significant reserves in Ukraine for the preservation of the achieved level of production and its capacity enhancement it is required to improve the systems of the existing fields development. According to the forecasts made, the solution of this problem is technically and technologically feasible.
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TRANSPORTATION OF OIL AND GAS

Ukrainian Gas Transmission System Renovation Project: Reliability and Efficiency of Gas Transit to Europe

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Public GSC «Ukrtransgaz»

The article is devoted to the problem of renovation of the Ukrainian gas transportation system. The main sectors and objects of renovation as well as their economic feasibility is shows.

1. Background

Russian gas export to the countries of Western and Central Europe and Turkey is carried out by three basic routes: through the gas-transmission system (GTS) of Ukraine, by the Yamal-Europe gas pipeline over the territory of Belarus and by the Blue Stream gas pipeline across the Black Sea. During the period of 2001-2010, the average amount of Russian gas transit through Ukraine was 110 bcma, given the gas transit system capacity is 146 bcma. In 2010 transit lowered to 95.4 bcm, this was almost 80 % Of all Russian gas deliveries to the mentioned countries. Due to putting in 2011 the North Stream into operation, the Ukrainian transit volume can decrease, but expected growth of gas consumption in Europe can be a substantial argument that Ukraine with its strategic pipeline infrastructure will remain a major route for Russian gas deliveries to Europe for decades.

It should be noted that Ukrainian GTS operates reliably today, providing deliveries of Russian gas to Europe under the contracted conditions. This is achieved due to flexibility and wide branching of the pipeline system and the cross-border pipelines, interaction between adjacent pipelines, considerable capacity of the underground gas storage (UGS) facilities located mainly in close vicinity to the EU borders, and by realization of technical inspection and rehabilitation programs, introduction of European operating standards and regulations. High qualification and experience of the personnel is although an important value.

2. Aims

In order to guarantee reliability and security of both gas supplies to internal users and transit gas deliveries to the European gas market for the future prospect, it is needed to provide accident-free, reliable, economically efficient and environmentally friendly functioning of all the GTS links . The tasks of the project are to conduct detail inspection of the GTS transit lines with subsequent replacement or renovation of the determined parts.

3. Methods

The aims can be achieved by systematic update and renovation of the GTS.

As far as some parts of the 12 thousand kilometers long transit gas pipelines have already been operated for 25-35 years, and many compressor units are outdated with low efficiency and high level of emissions, NaftoGaz of Ukraine together with EU experts, selected first priority lines and objects to be replaced or rehabilitated and upgraded.

The GTS Renovation project (Fig.) envisages: for the main gas pipelines:
- conducting technical inspections;
- replacement of defective parts of the gas pipelines;
replacement and / or repair of pipeline isolation;
replacement of fittings and valves;
modernization of remote control and telecommunication systems;
for the compressor stations:
Modernization or replacement of gas compressor units (drivers, superchargers);
modernization or replacement of the systems of compressor units automated control and electrical equipment;
modernization or replacement of auxiliary equipment;
replacement of fittings and valves.
The first priority objects for renovation are:
the Urengoy - Pomary - Uzhhorod, Soyuz and Prohres gas pipelines on the western transit corridor, and the Yelets - Kremenchuk Ananiiv - Izmail gas pipelines on the southern transit corridor;
The Bil'che-Volytsia-Uherske and Bohorodchany UGS facilities;
the Uzhhorod, Berehove, Drozdovychi, Tekove and Orlovka gas metering stations.

Basic characteristics of the selected gas pipelines

<table>
<thead>
<tr>
<th>Gas pipeline</th>
<th>Put into operation (year)</th>
<th>Length (km)</th>
<th>Working pressure (MPa)</th>
<th>Unit power (MW) and number of compressors</th>
<th>Mean operating life (hours)</th>
<th>Average efficiency (%)</th>
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<td></td>
<td></td>
<td>16/8</td>
<td>50</td>
<td>29</td>
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<td></td>
<td>25/12</td>
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<td>33</td>
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<td>Yelets-Kremenchuk-Ananiiv-</td>
<td>1986</td>
<td>930</td>
<td>7.4</td>
<td>6/15</td>
<td>33</td>
<td>23</td>
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<td>10/45</td>
<td>70</td>
<td>25</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16/4</td>
<td>60</td>
<td>To</td>
</tr>
</tbody>
</table>

Basic characteristics of the selected gas pipelines and compressor stations are presented in the Table. The characteristics of the Bil'che-Volytsia-Uherske and Bohorodchany UGS facilities are respectively as follows: working gas volume - 17050 and 2300 MMcm, maximal volume of gas withdrawal at the beginning of season - 142 and 50 MMcm / d.

The project envisages that the renovation works will be carried out without stopping or decreasing of transit gas shipping through Ukraine.

In accordance with the EU-Ukraine Declaration upon results of the International Investment Conference on Modernization of Ukrainian GTS held in March 23, 2009, it is expected that the EBRD and European Investment Bank will provide financing of the works. In July 2011 the first phase of the Renovation project on reconstruction of the Ukrainian part of the Urengoy-Pomary-Uzhhorod commenced.

4. Results
Realization of the Renovation project will provide:
- long term correspondence of the main gas pipelines characteristics to the design
parameters;
- higher efficiency of the compressor units;
- increase of the compressor units operation life to 100 000 - 150 000 hours;

5. Summary / Conclusions

Realization of the Renovation project will enable to provide until 2030 and for further prospect:
- reliable and uninterruptable transit gas deliveries at the level of 110-140 bcma;
- high commercial attractiveness of the system;
- competitiveness comparatively with alternative gas pipelines, which require considerable capital investments and building of new infrastructure.
Author of article

Lokhman Igor Leonidovych

Chief Engineer of Ukrtransgaz SE. Graduated from Ivano-Frankivsk National Technical University of Oil and Gas. His production interests are associated with the development of the concept of automated systems for electrochemical protection of facilities of the GTS of Ukraine, resource extension strategies and implementation of a complex of pipelines renovation technologies in Ukraine.
The paper describes the origin of petroleum refining industry and the current state of oil refining in Ukraine.

Petroleum industry emerged and developed in close cooperation with the extraction and consumption of oil and its processing products. The information on availability of oil in the Carpathian region has long been reflected in the geographical names of areas as Ropa, Ropyanka, Ropytsya etc., where the oil deposits came to the surface.

Up to the early nineteenth century oil has not gained wide use in the economy of ancient Galicia and in the world. Arguably, only the primitive methods of oil extraction and processing existed. It went about the various primitive techniques for extraction of thickened oil (without light components), which was used to grease the axles of carts. It was important during the widespread use of horse transport, but the commercial use oil was secondary. Only in 1810 the Austrian Government recognized oil and mineral wax the as raw material subject to the mining monopoly. Accordingly, it became necessary to obtain the permit for oil and wax extraction from the Department of Mining, located in Drogobych.

In the first half of the nineteenth century the interest in oil is growing, which soon was expected to have an important role in the further development of civilization, which is caused solely by the industrial revolution started in the second half of the eighteenth century.

This process, which later became worldwide, was initially stimulated by the need to find substitutes for scarce vegetable oils and animal fats, used for lighting in cities which were growing quickly due to industrial development and population growth.

The first attempts to obtain the product fit for lighting from oil and introduce the same for massive use were made in 1816 - 1817 in Galicia by J. Hecker and J. Mitis. The oil distillate resulting from petroleum distillation (in the way which is now forgotten) was used for lighting of streets in Drogobych and military barracks in the town of Sambir. Thereafter the production of distillate (lighting kerosene) was expanded. From the memoirs of a pharmacist, J. Zeg in the Almanac of a pharmaceutical association for 1889 it is known that the slave of Baytal performed the oil processing in 1830 in the village of Naguyevychi. For this he used a metal container with an attached stream from the gun cooled with water. He also received three fractions: gasoline, kerosene and bottoms. The gasoline and kerosene fractions were sold by him to Galician pharmacies and the bottoms was used to grease the wheels.

The second half of the nineteenth century was remarkable for the rapid growth in demand for lighting, as well as fuel to propel the steam engines. In this regard, all countries which at that time were mining, oil almost simultaneously intensified their activities towards the development of lighting kerosene. I. Lukasyevych was the first who achieved the positive results, which became crucial to the creation of oil extracting and refining industry. In 1853, I. Lukasyevych working as a pharmacist in Lviv pharmacy "Under a gold star", owned by Mr. Mikolyash, together with Jan Zeg,
obtained the kerosene which was suitable for the practical application by its properties, i.e. for lighting. This product (which they named camphene or new camphene) with the boiling point of 200-250°C was isolated from the distillation with a broad margin of boiling, previously obtained from oil by extraction of lower and higher boiling components by fractional distillation. Camphene was purified with sulfuric acid and sodium hydroxide. It was safe to use for lighting in the lamp of new design developed by I. Lukasyevych with a Lviv tinman, A. Bratkovskyi.

Mikolyash, Lukasyevych and Zeh Partnership entered into an agreement with a public hospital in Lviv on its lighting with kerosene lamps, pursuant to which they delivered 500 kg of kerosene and Bratkovsky supplied the required lamps to the hospital. On July 31, 1853 Lviv hospital was lit, where the first complex surgery was made at night by the light of kerosene lamps. This day went into history as the beginning of the world oil industry.

At the beginning of the second half of the nineteenth century Drogobych becomes a large, and subsequently the largest refining center in Galicia. In the late 19th and early 20th century the new oil (or as they were then called "gasoline") plants in Boryslav, Ulatovychi, Sambir, Stryi, Lviv appear in Galicia. In 1879 there were 36 plants registered, and after 10 years there became 57 of them. They produced 20,400 tons of petroleum products a year, and after 6 years their capacity reached 41,000 tons a year. These factories employed over 2,000 workers. As a result of this development, Galicia temporarily becomes the third after Russia and the United States world-class center for oil extraction and processing.

The first refinery in Drohobych was founded in 1859 by A. Schreiner. It was a small company which burned down later on. However, in 1863 a new joint venture of two owners G. Altman and J. Gottlieb was created at the same place, which has become the basis for the modern NPK-Galychyna OJSC (formerly Drogobytsky oil refinery). This plant later on was called Galicia. Therefore, the year of 1863 is rightly considered the beginning of the industrial re-working of oil in Ukraine.

In 1914, at Galicia refinery there were two oil refining installations, a periodic one, consisting of seven cubes, and a continuous, with twenty boilers, six of which are operated at atmospheric pressure, and three under reduced pressure (300 mm Hg). At installation of the periodic oil refining there were two cubes which carried out the filtrate distillation (obtained from paraffin oil), making it possible to extract the lubricating oil of the required quality. All this was provided by three bitumen cubes and ten cubes of thermal cracking.

During the interwar period Galicia refinery was built up to the capacity close to 140 tons a year, and in 1925 there was built Cross installation for thermal cracking, similar to that existing at the Vacuum Oil Company in Chekhovychi. This plant was the first in Poland which started manufacturing bitumen named Molfalt and Gambit. Its oils sold under the Galtol brand name worked well in the market.

Searching for the ways to use and sell oil discovered in Galicia, the extraction volumes of which were growing rapidly, the management of the National Oil Company in 1902 considered the issue of the beginning of petcoke for locomotives of Austrian railways. This led to the construction of a new refinery, which in 1919 was named Polmin.

In 1938, Polmin first introduced engine oil called Triselektol with viscosity index close to 100, obtained by selective refinement of oils with cresol, to the market. At the same time it was planned to build a plant for selective refinement of oils with furfural. The installation for oil treatment with sulfuric acid using centrifuges (making the cleaning process continuous, and reducing the consumption of acid), as well as a plant for calcium oil production were built too.

Introduction of a two-stage tubular installation distillation for oil distillation at Polmin significantly affected the increase in output, primarily the expansion of the range of bitumens, including for road, which were manufactured there. This method of oil distillation allowed obtaining the vacuum residue with stable properties and deep elimination of light fractions. These restudies were the raw material for the production of commodity road and industrial bitumens, and sometimes just finished products of this type.
In September 1939, both refineries in Drogobych were nationalized and became state property. The name of Polmin was changed for Drogobyskia refinery No. 1, and Galicia for Drogobyskia refinery No. 2.

Refining in the heart of oil extraction, i.e. in Borosyav, dates back to 1899, since the Galician oil company successfully drilled four wells with oil production of 40 t/h.

At early 1902 the citizen of Borosyav, Kornhaber, buys 0.25 hectares of land near the village of Hubachi (now a part of Gallak OJSC). This area was not chosen by chance; nearby there was the railroad which connected Borosyav with Drogobych. Three cube containers with the capacity of 0.5 m3 each are installed and the kerosene and gasoline production is started.

In 1910, the Refinery buys another 5 hectares of land and, having made use of the cheap oil, installs the distillers, which provided an opportunity to obtain the liquefied petroleum gas, gasoline, diesel fuel, paraffin oil and paraffin from petroleum. From Skhidnytska oil they produced the cylinder oil as coke waste. However, thereafter Refinery was behind Galicia and other refineries in Borosyav by its technical equipment.

The primitivity of technologies used at the Refinery can be demonstrated by paraffin production. The paraffin oil driven off from oil was poured into wooden barrels, which were buried in the ground for 2 to 3 months. After then the paraffin was pressed by hand presses in sacks. Thus obtained black wax sent to refineries for further processing. At the end of 1938 the plant operated for only one month a year, and for the remainder of the time (11 months!) it was in conservation.

In 1896 Lviv refinery was built. The owners of the refinery were Liansberg, Val, Baron, and since 1920 the Joint Stock Company of Oil Industry and Terrestrial Gas in Ukraine, founded by the Polish Regional Bank and Polish Industrial Bank. The plant occupied an area of 4.33 hectares, which housed the factory building, distillation, alkaline and acid installations, collections for gasoline, kerosene, heavy oils and oil, a warehouse of candles and paraffin, a room for workers and two houses. At the plant there were 11 small cubes 10 m3 each for rectification of oil, 13 machines for manufacturing of candles, a melting pot for paraffin and a generator to produce own power. In the boiler room there were two steam boilers. After plant expansion the oil distillation was carried out in two cubes 50 tons each. The process was organized in such a way that the oil field (in %): gasoline factions - 20, kerosene - 20, diesel fuel - 20, oil, engine oil - 15 and cylinder oil - 18. The distillation of gasoline fraction was carried out in the boiler with the capacity of 26 m3. The output products were heated by water vapor. Through coils, fractional columns and refrigerators the gasoline went into collections with a capacity of 170 m3. The plant had six such collections.

The kerosene passed the acid-alkaline purification in mixers with a capacity of 37 m3 each. Waste acid with asphalt were used in mixtures with coal as the energy fuel in the distillation cubes. The engine and cylinder oil was purified by acid-base method in two machines with mixers with a capacity of 28 m3 each. The performance of the oil treatment process was 21 tons a day.

![Figure. Dynamics of oil processing in Ukraine, mio t](image-url)
The year of 1931 became crucial for the plant because, according to the latest achievements of contemporary technology, the construction of the tubular system of Foster Willer system installation was commenced. This setting was to replace the old distilling equipment. The tank fleet also underwent the reconstruction.

After commissioning the Foster Willer unit worked for 14 days in ambient and for 14 days in vacuum mode for processing the heating oil and then repeated cycles.

In 1932 the plant began construction of the emulsions workshop, consisting of 80% refined and deodorized gasoline, 18.5% water and 1.5% emulsifier and intended for the chemical industry. The year of 1934 was remarkable for construction of facilities for oil dispensing and installation of filter presses. To improve the quality of gasoline obtained in distillation columns, it was mixed with ethanol, thus obtaining the so-called "gas-alinizine." In the same year the oil dewaxing plant was built. The plant water infrastructure also underwent reconstruction.

In 1939, after the consolidation of Ukrainian lands, the oil refineries were nationalized.

In 1897 the refinery was built in Nadvirna to process the crude oil from the surrounding villages Bytkiv, Pasichna, Kosmache etc. The oil is also brought in tanks from Boryslav.

In the 30s’ of the twentieth century the refinery in Nadvirna changed its owners several times. They were Romanian, French, Italian and British businessmen.

The oil was carried by its distillation in cubes with the capacity of 10 m3 each. Given that the oil Bytkivske deposit contained much paraffin, had a high setting point and was the main raw material, the plant only worked in summer. Five of the seven existing units worked simultaneously. The units were heated with wood or sawdust soaked in fuel oil. Such a cube installation yielded gasoline (end boiling point 225°C), kerosene (end boiling point 350°C) and fuel oil. The kerosene thus obtained was purified with sulfuric acid and alkali and rinsed with water. All transactions involving the supply of acid, alkali, water and mixing were carried out manually. The installations with mechanical mixing were introduced in the plant only in 1927-1928.

In 1936, for obtaining of paraffin oil, two large cubes with reflux were installed in the factory. The paraffin shop with the capacity of 40 tons per month was built. The paraffin oil was taken up to 400°C, which then yielded hard paraffin and diesel. In the paraffin plant there were four crystallizers and three filter-presses. The flowchart of paraffin obtaining was not fundamentally different from the standard one. In 1937-1938 the plant processed 750 tons of oil per month. At the end of 1938 its capacity reached 1,000 tons per month. In September 1939 the oil refining plant in Nadvirna, like all Carpathian plants, was nationalized. In 1940 here another cube of 24 m3 was installed and the plant capacity increased up to 1150 tons of oil a month.

In the territory of eastern Ukraine's the oil refining industry was initiated by cracking plant construction in Odessa (1935), Berdyansk (1936) and Kherson (1937).

During the postwar years two modern refineries were built in Kremenchuk and Lysychansk, and the plants in Drogobych, Lviv, Nadvirna, Odessa and Kherson were reconstructed and expanded, which promoted the increase of design capacities related to oil processing, the scope of which reached 62.5 mio tons a year in 1990 (table 1).
Table 1

Capacity of Ukrainian refineries related to initial processing of oil, million tons a year

<table>
<thead>
<tr>
<th>Refinery</th>
<th>Designed capacity in 1990</th>
<th>Technical capacity in 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINIK PJSC, Lysychansk</td>
<td>23.5</td>
<td>8.0</td>
</tr>
<tr>
<td>Ukrtatnafta PJSC, Kremenchuk</td>
<td>18.5</td>
<td>8.0</td>
</tr>
<tr>
<td>Khersonnaftopererobka PJSC, Kherson</td>
<td>8.7</td>
<td>–</td>
</tr>
<tr>
<td>Lukoil ONPZ PJSC, Odessa</td>
<td>3.9</td>
<td>2.8</td>
</tr>
<tr>
<td>NPK-Galychyna PJSC, Drogobych</td>
<td>3.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Naftohimik Prykarpattia PJSC, Nadvorna</td>
<td>3.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Lviv Research Oil and Lubricant Plant PJSC, Lviv</td>
<td>0.5</td>
<td>–</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62.5</strong></td>
<td><strong>22.6</strong></td>
</tr>
</tbody>
</table>

The oil and gas condensate can be processed in Ukraine at six refineries, Lysychansk, Kremenchuk, Odessa, Kherson, Drogobych and Nadvorna, as well as five gas distillation plants, the largest of which is Shebelynskyi and three units for processing the hydrocarbon feedstock. There are also about 20 mini-refineries with the total capacity up to 400 tons per year.

The Ukraine refineries had or have various technological installations, the processes at which are described in Table 2.

Table 2

Technology processes at Ukrainian refineries

<table>
<thead>
<tr>
<th>Refinery</th>
<th>Technology installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kremenchuk</td>
<td>Primary processing, catalytic reforming, catalytic cracking, hydrotreating of reactive and diesel fuels, selective clearing, dewaxing, hydrotreating of distillates, hydrotreating of paraffin, hydroisomerization of diesel fuels, MTBE production, bitumen production</td>
</tr>
<tr>
<td>Lysychansk</td>
<td>Primary processing, catalytic reforming, catalytic cracking, isomerization, hydrotreating of diesel fuels, production of MTBE, polymerization of propylene,</td>
</tr>
<tr>
<td>Kherson</td>
<td>Primary processing, catalytic reforming, coking, bitumen production</td>
</tr>
<tr>
<td>Odessa</td>
<td>Primary processing, catalytic reforming, catalytic cracking, isomerization, hydrocleaning of reactive and diesel fuels, production of MTBE, polymerization of propylene,</td>
</tr>
<tr>
<td>Drogobych</td>
<td>Primary processing, thermal cracking, catalytic reforming, coking, of producing bitumen</td>
</tr>
<tr>
<td>Nadvorna</td>
<td>Primary processing, catalytic reforming, coking</td>
</tr>
</tbody>
</table>

The reduction of oil processing in Ukraine (figure) led to the elimination of certain processes at refineries and suspension of production, particularly at the Kherson refinery.

The decline in oil processing in 2006 was associated with downtime of Odessa and Kherson refinery due to their modernization. In addition, this process was affected significantly by sharp rise in world oil prices and higher excise duty on Russian oil, which from $35 per ton in 2004 increased to $250 per ton in 2006. Under these conditions, at a relatively low depth of oil processing at Ukrainian refineries, the oil export has become more profitable for Russian oil companies. The increase in the world oil prices also played a positive role in the development of the Ukrainian oil extraction and increase of the oil depth processing parameter at all existing refineries.
After analyzing the data of table 3 we wondered why the Ukrainian oil refiners in 2011 lost nearly a fifth of the volume of oil. The main reasons include the higher oil prices and lack of support from the state. In March 2011 a memorandum with refinery owners was signed, but the state almost defaulted.

In Ukraine today there are left two plants which may produce oil; the western factories do not work. Odessa Lukoil was unable to defend its assets, and therefore stopped the production. The situation with the reconstruction of Kherson refinery is unclear.

Working in market conditions, and Kremenchuk and Lysychansk refineries began solving their immediate problems independently. Ukrtaatnafta PJSC chose the path of reduction of its production 15% and cutting down the imports of Azeri oil. LINIK PJSC decided to leave the production of no more than 50 to 90 thousand tons of light products in Ukraine.

Still it is worth noting that Ukrtaatnafta PPSC launched the production of gasoline with improved performance (Euro-4) in 2011, which was possible due to the upgrade of the hydroconversion unit of section 200 of installation JIK-6y for hydroconversion of catalytic cracking gasoline. Due to the construction of dewaxing installation jointly with Shell Criterion, which gave the company an opportunity to produce 70 to 90 tons of winter and arctic diesel fuel monthly, we managed to survive the cold winter of 2012. The building of installation for isomerization of light gasoline fractions and hydroconversion of catalytic cracking with the capacity of 380 and 600 tons respectively by Ukrtaatnafta PJSC will give the opportunity to obtain gasoline with a sulfur content less than 10 mg/kg and aromatics content not more than 35%.

In 2011, from among all refineries of Ukraine, the Lysychansk LINIK looked most attractive. Loading with primary processing per month amounted to 350-450 thousand tons. The plant is producing gasoline of Euro 4 standard and plans to produce Euro 5. Since September 2011 the company produces diesel fuel with a sulfur content of 10 ppm. Now such diesel (Standard 5) accounts for 30% of the total diesel fuel produced.

The perspectives of Lukoil ONPZ JSC are not defined. In 2005-2008, the production suspension was caused by the plant reconstruction. In 2008-2010, the plant produces the products which serve as raw material for the Balkan enterprises of Lukoil. In the future, maybe, it will work on Azeri oil. NPK-Galicia and Naftokhimik Prykarpattia reduced the volume of oil refining almost twice. Some local oil is forwarded to Ukrtaatnafta PJSC. The oil from Azerbaijan turned out to be too expensive for these companies too. The reconstruction works are frozen and the staff is dismissed.

As regards Kherson refinery, it is not working for more than six years already. The plant undergoes a complete reconstruction. It is hoped that in 2015 the plant will work and produce Euro 5 standard.

The author believes that only through joint efforts of the owners of enterprises referred to

### Table 3

<table>
<thead>
<tr>
<th>Refinery</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kremenchuk</td>
<td>3121.8</td>
<td>3611.9</td>
<td>3119.0</td>
</tr>
<tr>
<td>Lysychansk</td>
<td>4952.8</td>
<td>4811.5</td>
<td>4946.4</td>
</tr>
<tr>
<td>Kherson</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Odessa</td>
<td>2051.6</td>
<td>1488.4</td>
<td>-</td>
</tr>
<tr>
<td>Drogobych</td>
<td>422.9</td>
<td>373.0</td>
<td>165.7</td>
</tr>
<tr>
<td>Nadvrina</td>
<td>155.3</td>
<td>195.9</td>
<td>137.8</td>
</tr>
<tr>
<td>Shebelynno</td>
<td>-</td>
<td>659.9</td>
<td>680.28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10771.4</td>
<td>11140.6</td>
<td>9049.18</td>
</tr>
</tbody>
</table>
herein and correct state policy for the introduction of import duties on petrochemicals we can overcome the crisis in the Ukrainian oil processing.

References


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Bratychak Mykhaylo Mykolayovych

He graduated from the Faculty of Technology of Organic Substances of the Lviv Polytechnic Institute, Doctor of Chemical Sciences, Professor, Academician of UNGA.

Since 1994 he has been working as a manager of department of chemical technology for oil and gas re-processing of the Institute of Chemistry and Chemical Technology of the Lviv Polytechnic National University (Lviv).
On February 15, 2013 a well-known industry expert, Mykhaylo Matsyalko, celebrated his 80th birthday. He was born in the village of Batyatychi, Kamyanka-Buzkyi district, Lviv oblast. After graduation from Lviv Housing and Communal College, Mykhaylo continued his studies at the Lviv Polytechnic Institute. He started working yet in 1964 in the Lviv branch of Dipromist. During the period from 1967 to 1970, working in the gas sector, he held the position of the chief engineer of the building administration and chief engineer of Lvivgaz trust. In 1970 Mykhaylo was appointed as a deputy of Lviv Regional Department of Housing and Communal Economy and then its manager.

At the responsible office of the Chief of Golovgaz of the Ministry of Housing and Communal Economy of USSR, Mr. Matsyalko has been working since 1974 and was a member of the Ministry board.

In 1975 Mykhaylo initiated the establishment of Ukrgaz and led its republican union. In 1992 the association was reorganized into the Ukrgas Ukrainian Corporation, the head of which was elected Mr. Matsyalko.

It is through perseverance of Ukrgas led by Mr. Matsyalko and active support of the President of the National Academy of Sciences of Ukraine, Borys Paton, that the production of special polyethylene product for gas supply facilities was launched in the country within a short time. For adoption of international experience in technology of polyethylene pipelines production Ukrgas and Gaz de France created a joint venture, Ukrfrahaz, in Ukraine.

Heading the regional and national organizations in 1996, Mykhaylo made a significant contribution to the development of gasification, accident-free and uninterrupted gas supplies to Ukrainian consumers. To improve the supply of liquefied natural gas for Ukraine's population, 22 new gas filling stations were built and seven LNGs were renovated under the direct leadership of Mr. Matsyalko. The gasification of Ukrainian settlements was developed particularly actively after creation of four powerful construction and commercial trusts, such as Kharkiv, Ivano-Frankivsk, Khmelnytsk and Kryvyi Rig, which consolidated 42 contracting gas installation administrations.

The contractors built annually over five thousands of underground pipelines and supplied natural gas to over 450,000 flats of the housing stock. On the initiative of Mr. Matsyalko, to improve the efficiency of gas supply systems, the construction of underground polyethylene gas pipelines in the villages of Novoodeskyi district in Mykolaiv oblast was started in 1981, jointly with Paton Electric Welding Institute.

Mr. Matsyalko has pioneered the manufacture of domestic gas meters for the purpose of gas accounting in Ukraine. Currently, eight Ukrainian factories manufacture such types of meters.
Under the supervision of Mr. Matsyalko, the housing, child care, recreation and health centers were erected for gas industry workers in all regions of Ukraine, in particular, Synyogora sanatorium in the Carpathians, Arnica in Truskavets, holiday homes in Lviv, Kharkiv, Donetsk, and Dnipropetrovsk. Dnipro camp for 360 persons was built in Arabat spit.

In 1990, Mykhaylo was elected the deputy of Ukraine.

In 2003 he returned to Lviv, where he created and headed the refreshment courses for engineers and technicians of Ukrainian gas companies, and in 2009 he retired.

Mykhaylo Matsyalko is the Chairman of the Association of the Gas Market Companies, a member of the Academy of Ukraine. He participated in liquidation of the Chornobyl disaster consequences.

For significant contribution in the development of the gas sector, personal merits in gasification of rural areas, and introduction of the scientific and technological progress achievements in production, in 1993 Mr. Matsyalko was awarded the honorary title of the Honored Worker of the Service Industry of Ukraine. In his arsenal of awards he also has the Order of Friendship of Peoples, medal for Labour Valour, honorable diploma of the Verkhovna Rada and the Cabinet of Ministers of Ukraine etc.

We wish good health and long active life to the hero of the day!

Friends, colleagues, editors
Features of the unconventional gas deposits development

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O.R. Kondrat Candidate of technical sciences IFNTUOG

This article generalizes the data on reserves and production of shale gas in different countries. It also analyzes the peculiarities of the geological structure and development of the shale gas and gas in dense rock deposits. As to the development of shale gas deposits with a net of horizontal wells with multi-stage hydraulic bed fracture, it presents the effect of the factor of the rock matrix permeability, half-length fracture and the distance between fractures on the gas recovery.

One of the directions of increase in production of natural hydrocarbons in Ukraine is to involve the unconventional gas deposits in the development. The current state of development of such deposits is characterized by a significant increase in gas production from shale and tight rocks in the United States, its production commencement in Canada, research of the issues of unconventional gas extraction in many countries (Australia, China, Germany, the United Kingdom, Sweden, Poland etc.).

Yet in the 19th century it became known that shales enriched with organic matter contain gas. The first well from which the industrial flow of gas from Devonian shale formations was obtained was drilled in 1821 in the Fredenia area, NY.

In the 20s’ of 20th century, the large-scale development of shale gas (Big Sandy Field, Kentucky) was performed for the first time. On the verge of the 50s’ and 60s’ years of the last century the method of hydraulic stimulation of the layer in wells extracting the gas from shale was tested for the first time.

In the 70s’ years of the 20th century in the United States the exploration work was carried out, during which four huge shale structures, Barnett, Haynesville, Fayetteville and Marcellus, occupying ten thousand square kilometers, were found. A new stage in the industrial extraction of shale gas began during the 80’s and 90’s of the last century. Several small companies, the largest and the most active of which was Chesapeake Energy, decided to return to the idea of extracting gas from shale beds. The main strategy has been drilling horizontal wells for shale gas extraction.

Today, in the U.S. the gas from shale is mined from more than 40,000 wells with more than 20 deposits, and the volume of its production in 2011 amounted to about 150 billion m3 [1, 2].

Shale gas is the gas found in fine-grained sedimentary rocks (usually of thermogenic origin), which are characterized by a relatively high content of organic matter, have low porosity and very low permeability. The slate rocks are characterized by layered structure and are penetrated with a grid of vertical and inclined cracks crossing the horizontal placement of the rock strata.

The required conditions for shale gas emergence are:

high content of organic matter;
relatively large thickness of the formation;

high thermal maturity of rocks and relatively small depth of their occurrence (up to 3000 to 4500 m).

Typically, the natural permeability of the shale rock matrix is in the range of $0.01 \cdot 10^{-6}$ m cm$^2$ to $0.01 \cdot 10^{-3}$ m cm$^2$.

The shale gas clusters are characterized by very large geological reserves with a low gas extraction coefficient. The shale gas consists mainly of methane and its homologues (ethane, propane, butane) mixed with hydrogen sulfide, carbon dioxide, nitrogen, hydrogen and helium, sometimes the increased radon content is observed [3].

Usually it is dry gas.

Another source of natural gas is the gas located in dense low-permeable sandstones, mudstones and other rocks. To extract this gas, it is required to use the agents to stimulate the reservoir. The permeability of these rocks is typically less than $0.1 \cdot 10^{-3}$ m cm$^2$. The pores in tight sandstones are distributed very unevenly, do not form a single pore space and are connected only by narrow capillaries, which leads to a very low permeability of the sandstone.

The main parameters of oil and gas systems are: a source of gas, parameters of traps, role of fluid stoppers, system physical characteristics (porosity, permeability) and temporal characteristics (time of accumulation and migration of gas). The gas deposits in tight sandstone are closer by its geological characteristics to traditional gas deposits than to the alternative ones. However, their physical and lithological characteristics are unconventional. Their feature is also the fact that thick sandstone is a reservoir rock, while the slate simultaneously serves as the rock collector, and parent rock. However, since the gas-containing tight sandstones and slates require artificial stimulation to extract gas, so they belong to unconventional sources.

The general comparison of the number of mining and reservoir characteristics of the shale gas, gas from tight reservoirs and conventional sources are given in Table 1 [2].

As can be seen from table 1, the shale gas is self-formed. It is not trapped and is dispersed all over the layer, the formation of which is continuous and unbroken. The tight rock gas and natural gas are peculiar of stratigraphic trap and lenticular/layered formation. Gas in shale rocks can be either in the free state, or be absorbed in the rock or dissolved in the fluid, and the actual rate of gas extraction does not exceed 35%, while the gas of tight rocks and natural gas is located in the pores and the coefficient of gas extraction for them is 45 and 95% respectively. It should be noted that the deposits of shale gas and tight rocks gas are characterized by low permeability. Therefore, for the commercial extraction of gas it is required to use the technology of hyperhydraulic layer fracturing (HLF).

The conventional global shale gas resources constitute 704 trillion m$^3$. Taking into consideration the relevant factors affecting the rate of the gas extraction, the technically extractable global shale gas resources are estimated at 181 trillion m$^3$. The distribution of geological/technically extractable resources of shale gas by continent (trillion m$^3$) is as follows: North America - 190.2/48.7; South America - 129.4/34.7, Europe - 73.3/17.7; Africa - 112.2/29.5; Asia - 160.3/39.8, Australia - 39.1/11.2.

The largest shale gas resources are concentrated in Asia (China), South America (Argentina, Brazil), Africa (South Africa), North America (USA, Canada and Mexico) and Australia. In Europe the greatest shale gas resources are located in France; however, the government of this state prohibited the development and production of shale gas for a number of the reasons.

So, we have very little information about the shale gas resources in Russia, which despite its global leadership in the export of natural gas today does not want to develop this area.
Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Shale gas</th>
<th>Gas from compacted collectors</th>
<th>Conventional gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>Self-formed</td>
<td>Migrated</td>
<td>Migrated</td>
</tr>
<tr>
<td>Trap</td>
<td>None</td>
<td>Stratigraphic</td>
<td>Structural/stratigraphic</td>
</tr>
<tr>
<td>Formation</td>
<td>Solid, continuous</td>
<td>Lenticular/layers</td>
<td>Lenticular/layers</td>
</tr>
<tr>
<td>Depth, m</td>
<td>610-4570</td>
<td>to 6100</td>
<td>from shallow to deep</td>
</tr>
<tr>
<td>Thickness, m</td>
<td>15-180</td>
<td>610-1370</td>
<td>30-300</td>
</tr>
<tr>
<td>Permeability, nano mcm²</td>
<td>&lt;0,1•10⁻³ mcm²D</td>
<td>Up to 500•10⁻³ mcm²</td>
<td></td>
</tr>
<tr>
<td>Porosity, %</td>
<td>6-12</td>
<td>7-15</td>
<td>14-25</td>
</tr>
<tr>
<td>Gas</td>
<td>free/adsorbed/dissolved</td>
<td>in pores</td>
<td>in pores</td>
</tr>
<tr>
<td>Actual gas extraction coefficient, %</td>
<td>25-35</td>
<td>25-40</td>
<td>to 95</td>
</tr>
<tr>
<td>Organic carbon content</td>
<td>Available</td>
<td>Unavailable</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Seismicity</td>
<td>yes, 3D</td>
<td>yes, 3D</td>
<td>Yes</td>
</tr>
<tr>
<td>Well type</td>
<td>Horizontal</td>
<td>horizontal/vertical/S-shaped</td>
<td>horizontal/vertical</td>
</tr>
<tr>
<td>Layer hydraulic fracturing</td>
<td>Performed to allow commercial production</td>
<td>Performed to allow commercial production</td>
<td>Performed to increase the extraction/removal of complications</td>
</tr>
<tr>
<td>Fluid stoppers</td>
<td>grasped by absorption of rock matrix (traps and fluid stoppers are not required)</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>Time factor (formation and migration)</td>
<td>the time is not essential, it is important only in the context of aging and generation of gas due to organic matter</td>
<td>essential for generation and migration from source and localization in traps</td>
<td>essential for generation and migration from source and localization in traps</td>
</tr>
<tr>
<td>Method of extraction</td>
<td>Hydraulic fracturing</td>
<td>Hydraulic fracturing</td>
<td></td>
</tr>
<tr>
<td>Fluid (water)</td>
<td>No water</td>
<td>The water extraction is possible</td>
<td>The water extraction is possible</td>
</tr>
<tr>
<td>Condensate</td>
<td>Little/mainly dry gas</td>
<td>Little</td>
<td>Contained in gas in varying amounts</td>
</tr>
</tbody>
</table>

Figure 1. Dependence of gas extraction coefficient on the number of wells in the area of Marcellus deposit for varying lengths of its development (basic version): 1 - 10; 2 - 60 years

The global gas reserves in dense rocks are 209.3 trillion m³ according to some estimates and about 850 trillion m³ according to the other [4].

The gas stock in dense rocks in the amount of 209.3 trillion m³ are distributed as follows (trillion m³): North America - 38.8; Central/Eastern Europe - 36.6; Sahara (Africa) - 9.9; Asia
Pacific – 2.2, South America - 25.5; countries of the former USSR - 23.3; central part of Asia/China - 22.2; South Asia - 9.9; Western Europe - 19.9; North Africa - 15 5; Pacific– 5.5. At present, there is almost no region in the world, which would not show interest in prospecting, exploration and increase of the resource base of natural gas in tight formations.

Table 2 shows the geological and physical features of selective formations of shale gas in Ukraine and world. The analysis of the data from table 2 shows that the prospective shale gas basins located in Ukraine have quite high geological and physical properties. The depth of shale in the Dnieper-Donetsk basin (PPD) account for 1,500 to 4,500 m, and in the Lublin Basin - from 1,500 to 2,800 m. As for the values of thermal maturity $R_o$ the shale rocks of Lublin basin and DDB are approximately one-term with the European ones (0.8 to 1.5%), but still are inferior to the American ones by the content of carbon TOC (0.5 to 5.5%). However, the effective thickness does not differ from global indices and varies from 30 to 100 m Given that the mining resources based on risks for the whole Ukraine are about 8.72 trillion m$^3$, the aforesaid promising pools represent a huge potential whereby the volume of domestic gas production may increase due to the development of deposits of unconventional gas.

![Graph](image)

Table 2

<table>
<thead>
<tr>
<th>Continent/Region</th>
<th>Pool</th>
<th>Formation</th>
<th>Age</th>
<th>Promising area, km$^2$</th>
<th>Depth, m</th>
<th>$R_o$% (In brackets - mean)</th>
<th>TOC% (in brackets - mean)</th>
<th>Clay content</th>
<th>Depth (effective), m</th>
<th>Extractable gas resources, taking into account the risks, trillion m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. America</td>
<td>USA Barnett</td>
<td>Lower Carboniferous C1</td>
<td>600</td>
<td>13000</td>
<td>2155-2833</td>
<td>1,3–1,7</td>
<td>4,5</td>
<td>Low</td>
<td>133,3–200</td>
<td>1,25</td>
</tr>
<tr>
<td>N. America</td>
<td>USA Fayetteville</td>
<td>Lower Carboniferous C1</td>
<td>1100</td>
<td>23400</td>
<td>333-2333</td>
<td>1,2–1,8</td>
<td>4,0–9,8</td>
<td>Low</td>
<td>6,7–66,7</td>
<td>1,18</td>
</tr>
<tr>
<td>N. America</td>
<td>USA Haynesville</td>
<td>Yura (upper) J</td>
<td>600</td>
<td>23400</td>
<td>3500-4500</td>
<td>3,5–3,7</td>
<td>0,5–4,0</td>
<td>Low</td>
<td>66,7–100</td>
<td>7,12</td>
</tr>
<tr>
<td>N. America</td>
<td>USA Marcellus</td>
<td>Middle Devonian  D2</td>
<td>600</td>
<td>247000</td>
<td>1333-2833</td>
<td>3,0–3,4</td>
<td>3–12</td>
<td>Low</td>
<td>16,7–66,7</td>
<td>7,42</td>
</tr>
<tr>
<td>N. America</td>
<td>USA Woodford</td>
<td>Upper Devonian D3</td>
<td>600</td>
<td>286000</td>
<td>2090-3666</td>
<td>2,7–3,3</td>
<td>1–14</td>
<td>Low</td>
<td>60–73,3</td>
<td>0,32</td>
</tr>
<tr>
<td>Europe</td>
<td>Poland Baltic Basin</td>
<td>Silurian Shales S1</td>
<td>600</td>
<td>22911,03</td>
<td>2499-4996</td>
<td>1,5 (1,15)</td>
<td>&lt;10 (4)</td>
<td>Medium</td>
<td>96,32</td>
<td>3,65</td>
</tr>
<tr>
<td>Europe</td>
<td>Poland Lublin Basin</td>
<td>Silurian Shales S1</td>
<td>600</td>
<td>30199,26</td>
<td>1999-4099</td>
<td>1,25 (1,35)</td>
<td>1–1,7 (1,5)</td>
<td>Medium</td>
<td>69,49</td>
<td>1,25</td>
</tr>
<tr>
<td>Europe</td>
<td>Poland Podlasie Depression</td>
<td>Silurian Shales S1</td>
<td>600</td>
<td>3451,73</td>
<td>1749-3459</td>
<td>(1,25)</td>
<td>&lt;20 (6)</td>
<td>Medium</td>
<td>90,53</td>
<td>0,40</td>
</tr>
<tr>
<td>Europe</td>
<td>Ukraine Dnieper-Donetsk Basin</td>
<td>Upper Devonian shales D3</td>
<td>600</td>
<td>1311,00</td>
<td>2000-3000</td>
<td>0,8–1,55</td>
<td>2,5–5,5</td>
<td>Medium</td>
<td>40,00</td>
<td>1,15</td>
</tr>
</tbody>
</table>
There are the following statements about shale gas: "No two shales are the same," "There is no simulation model that would fit for all shale wells." Wells in shale and tight rocks, which were subjected to hydraulic layer fracturing (HLF) have quite non-standard nature of attrition. The initial gas flow rate is relatively small, from 60,000 to 280,000 m$^3$/day (for horizontal wells). The rate of reduction of the gas flow rate is quite high. During the first year the gas flow rate may be reduced to 65-80% of the original, during the second - up to 35-45%, and during the third - 20-30%. Then the gas flow rate is reduced by about 5% per year. This low flow rate, or as it is called, the "tail" can be sustained for 25 to 30 years [2].

The development of areas of unconventional gas is complex a process where the technical, commercial and environmental issues are closely related and play an important role in determination of the economic attractiveness of the project. The uncertainty of many variables, especially the geological data, wells productivity efficiency, and the cost of wells construction play a dominant role during the development of deposits. The requirements for infrastructure, especially in the early life cycle of the project, can provide a significant impact on the project economy.

The production data for major shale gas deposits of the USA imply that the total number of wells to develop the general extractable stocks should be provided by production of 30 billion m$^3$ by 200-300 wells [2].

There are five life cycles of the shale gas and tight rocks deposits, i.e. exploration, evaluation, drilling, extraction and reclamation. According to the American scientists [4], at the phase of restoration it is worth applying the re-fracturing. It is known that the flow rate of gas from unconventional wells rapidly decreases, reaching the unacceptable levels after just a few years of extraction. The re-fracturing allows increasing the technological parameters of gas production.

Determination of the optimal number of wells at non-conventional deposits is an important task [5]. The peculiarity of development of such deposits is the consideration of both engineering and economic risks, including the permeability reduction due to compaction of rock and quality of completion of wells.

It is known that high performance is achieved upon tight placement of cracks. It is believed that when the distance between the cracks is about 15 m or less, they are less effective because of stress in the rock. The effectiveness of proppant and conductivity of cracks are also important for wells productivity.

The distance between the cracks is defined as the distance between two adjacent flat hydraulically induced cracks along the borehole. Hence the term of the "stimulated deposit volume" (SDV). SDV is the total area covering all cracks, i.e. from the beginning to the end of the crack. EDV (external deposit volume) is the area outside SDV, which is defined for a particular well based on impermeable boundary of its reservoir.

<table>
<thead>
<tr>
<th>Europe</th>
<th>Ukraine</th>
<th>Lower Carboniferous Basin</th>
<th>Dnieper-Donetsk Basin</th>
<th>Mid-coal shale</th>
<th>Lublin Basin (Volyn-Podillia)</th>
<th>Silurian shales</th>
<th>Ci</th>
<th>1714.00</th>
<th>1500-4500</th>
<th>0.8-1.1</th>
<th>1.1-2.7</th>
<th>Medium</th>
<th>40-70</th>
<th>2.39</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C1 3027.00 1500-4000</td>
<td>0.8-1.15</td>
<td>1.2-2.8</td>
<td>30-60</td>
<td>4.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2 2657.00 1500-2800</td>
<td>0.8-1.5</td>
<td>0.5-2.2</td>
<td>80-100</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* - Initial promising areas of search for shale gas in Ukraine
The data from Marcellus and Haynesville shale deposits were used to study the optimum distance between wells for various matrix permeability options \((5 \cdot 10^{-9}, 50 \cdot 10^{-9}, 500 \cdot 10^{-9} \text{ mcm}^2)\), half-length of the crack (75, 150 and 275 m), the distance between the cracks (12, 18, 24, 36 and 48 m). [5] The studies used the following mean values of Marcellus and Haynesville deposits: the depth of the layer roof – 3,627 and 2,095.5 m, the thickness of the reservoir - 61 and 71.6 m, porosity - 8 and 4.8%, initial reservoir pressure - 69 and 28.3 MPa, and relative density of the gas - 0.593 and 0.57. The properties of Haynesville deposit were determined using an average of 100 different wells along the area. The properties of Marcellus deposit were taken on the basis of mean values of 160 wells of Tioga county, Pennsylvania. The length of the horizontal section of wells was the same for all options, i.e. 1,170 m. The lateral trunk is placed in the middle of the deposit thickness. The basic option for Marcellus and Haynesville deposits was the matrix with permeability of \(50 \cdot 10^{-9} \text{ mcm}^2\), the distance between the cracks is 25 m, which corresponds to 48 cracks, and the crack half-length is 150 m. The following maximum gas flow rates were investigated: for Marcellus deposit - 85 thousand m\(^3\)/day and for Haynesville deposit 170 thousand m\(^3\)/day.

In studies assumed that all wells are placed evenly over the area, draining the homogeneous reservoir area of 2.6 km\(^2\), are put into operation simultaneously and are operated with a constant gas flow rate until the pressure at the wellhead is reduced to a pressure in industrial pipeline. Thereafter the wells are operated at a constant working pressure at the mouth (1.7 MPa).

According to the calculations (Fig. 1), the rate of gas extraction, as well as a combined net profit reaches the maximum value on five wells. Upon further increase in the number of wells the gas extraction ratio increased only slightly, and the cumulative net income is reduced.

The basic option provides for cracks with the half-length of 150 m. The SDV of each well extends to 304.8 m (152.4 m in each direction). Five wells form a total SDV length of 1,524 m of the possible 1,609 m, like at the area of 2.6 km\(^2\). The optimum distance between wells is well correlated with SDV length.

For comparison with the basic option, the other options changed the value of the matrix permeability, crack half-length and the distance between the cracks.
Fig. 2 shows the dependence of the gas extraction coefficient on the number of wells for half-length crack of 75, 150 (basic option) and 275 meters. For half-length cracks 75 m the maximum gas extraction coefficient is achieved only on eight wells in the area, but still is less than the other values of the half-length crack. For half-length crack 275 m the maximum gas extraction coefficient is achieved in three wells. The same gas extraction coefficient is the case for half-length crack of 150 m in the presence of five or more wells. The results indicate the importance of the SDV and EDV ratios. To maximize the gas extraction SDVs of each well should contact with each other.

The permeability effect on the gas extraction coefficient is shown in fig. 3. For $5 \cdot 10^{-9}$ mcm$^2$ permeability the gas extraction coefficient on five wells reaches only 50%. For all models with $5 \cdot 10^{-9}$ mcm$^2$ permeability the net cumulative income was negative or below the minimum 10%, indicating a lack of economic feasibility of the development of the area with rocks permeability of $5 \cdot 10^{-9}$ mcm$^2$. The option with $500 \cdot 10^{-9}$ mcm$^2$ permeability has the highest value of the net cumulative income. As shown in Fig. 3, the optimum number of wells in this case will be four (for the basic penetrability of $50 \cdot 10^{-9}$ mcm$^2$ the number of wells shall be five). Thus, the external flow from this matrix can be significant for permeability values of $500 \cdot 10^{-9}$ mcm$^2$ and more.

In experiments with various distances between the cracks it was assumed that the hydraulic cracks are distributed evenly along the perforated horizontal site so that 96 cracks have a 12-meter distance between the cracks and 24 cracks have a 48-meter distance.

The dependence of gas extraction coefficient on the smallest and biggest distances between the cracks is shown in Fig. 4. For a distance of 48 m the gas extraction coefficient reaches 58% with five wells in the area. For a distance of 12 m the gas extraction coefficient is 66%, also with five wells in the area. The smallest spacing between the cracks provided the maximum values of the net cumulative income and gas extraction coefficient. For the distances less than 24 m, the gas extraction coefficient is increased by less than 5%. The analysis of the research findings shows that the optimal interval between cracks ranges from 24 to 30 m, if the half-length crack is 150 m (basic option).

Thus, the findings of study of the optimal distance between wells during shale gas extraction in the case of Marcellus and Haynesville deposits show that the net cumulative income for the basic option of the matrix permeability of $5 \cdot 10^{-9}$ mcm$^2$ begins to decline after 10 years of gas extraction if there are more than five wells. So the best option for the area of 2.6 km$^2$ is five wells. The maximum gas extraction coefficient can be achieved when the SDVs and EDVs of each well contact. In the case of matrix permeability of $500 \cdot 10^{-9}$ mcm$^2$, which is ten times more than the basic option, the optimal number of wells in the area of gas content is four. The influence of matrix permeability on
The gas extraction coefficient showed that the outer flow from the rock matrix can become significant when the value of the permeability is $500 \cdot 10^{-9}$ m cm$^2$ and more. It was found that the optimal spacing between the cracks is 24 to 30 m.

The findings of the presented researches describe the impact of natural and technological factors on the shale gas extraction coefficient. Method [5] can be used to select the optimal option for the design and development of shale gas deposits in Ukraine.

Analyzing the data from current and future formations of shale gas in the world and in Ukraine, it can be assumed that all the criteria of the prospective areas for shale gas in Ukraine generally meet the European ones (by the content of clay, geological age, $R_0$ values, TOC, effective thickness). The shale gas deposits in North America have better geological and physical characteristics.

Mastering of the unconventional gas spaces is a complex process where the technical, commercial and environmental issues are very interrelated to determine the economic attractiveness for the project. The uncertainty of many variables, especially the geological data, wells productivity, and the cost of well construction is dominant throughout the period of development of deposits.

To mitigate the risks, it is recommended using a series of the life cycle phases of the shale gas with clear criteria for deciding on the subsequent of the project for investigation and subsequent development of the promising areas, i.e. exploration, evaluation, drilling, extraction and reclamation.

The key factors for successful development of unconventional gas reserves remain for many years (and will remain) are the drilling of operational horizontal wells and performance of a multi-grade hydraulic layer fracturing therein.

These two factors reflect the fundamental differences between the development of unconventional and traditional gases. The natural gas deposit is the uniform hydrodynamic system. Therefore, its design provides for control and management of the process of fluid movement in the reservoir to the extraction wells, determination of the key averaged development indicators (average single well production rate, average reservoir pressure, etc.). The development of unconventional gas deposits is discrete and actually connected to the control and management of each well operation processes. Since the unstimulated gas-containing rocks of unconventional gas (matrix) have very low permeability, the fluid filtration to the downhole almost does not occur. By drilling horizontal shafts and performance of multiple hydraulic layer fracturing the simulated deposit volume is formed in the well, which is the main source of gas during the entire period of operation of a economically viable well. Thus, when drilling a grid of wells in the unconventional gas deposit the wells should be placed so that their SDVs contacted with each other or at least overlapped to prevent the well interference phenomenon.

The above difference between the conventional and unconventional gas deposits explains the inability to use the existing analytical approaches for calculation of development performance and evaluation of the layer hydrodynamic properties. To do this, it is required to apply the different techniques, including the decline analysis method according to Arps, Argaival-Gardner, Fetkovych’s curves and plotting of the gas flow rate dependence and accumulated gas collection on the time in bilogarythmic scale subject to determination of various modes of gas filtration, i.e. non-linear, pseudolinear, radial, pseudo-pseudostationary and pseudostationary flows. These methods make it possible to predict the gas production over time, to evaluate various well parameters, such as half-length of the crack, crack conductivity, skin effect, SDV limits, potentially recoverable well reserves etc. In addition to the aforesaid techniques it is required to apply the numerical modeling of the process for extraction of unconventional gas from wells, including the principle of dual porosity and Voronoi’s grid, using the special software (e.g. Eslipse, CMG, etc.)
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Authors of articles

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Jordan and Iraq Will Build the Pipeline

Jordan and Iraq agreed to build a pipeline to supply oil to Jordan. The pipeline will transport oil to a refinery in Zarha to meet Jordan needs and to the only Jordanian port of Aqaba for its export. The total capacity of the pipeline is estimated at 160 thousand m$^3$ per day. Jordan and Iraq also agreed to increase the volume of oil to be delivered to Jordan from 1.6 to 2.4 thousand m$^3$ per day.
HEALTH AND ENVIRONMENT

The problems of urban areas upon development of oil and gas fields (with reference to Boryslav)

UDK 622.276:504.550.43 (477.8)

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The article analyzes the scientific works regarding the research area in question. It contains the findings of research of gas pollution in Boryslav and shows the results of hydrocarbon concentration measurements taken in the basements of houses in the territory of Boryslav. The authors have worked out and suggested the measures for reduction of the level of gas pollution.

Boryslav oil field is a unique natural and man-made system having no analogue in the world.

The first mention of oil in Boryslav is dated back to the second half of the eighteenth century. In 1810 the Government of the Austrian Empire issued a Decree of the Court House, pursuant to which oil was recognized as a mineral and the state monopoly for oil and wax extraction was established. To extract oil, it was required to obtain a license from the Department of Mining, which was located in Drohobych. That same year the first permits for oil extraction were issued. Due to significant oil manifestation on the surface from Vorotyshche and Polyany Neogene sediments of Boryslav hollow folds, the field development with manholes and then with shallow wells was started. The boring of deep wells in the deposits started in 1886. The major horizon oil field is Boryslav sandstone of Boryslav hollow folds, discovered in 1887. At present, there are more than 2,000 wells and more than 20,000 pits in the city [1-3].

The long-lasting oilfield activity used to be, and nowadays is accompanied by worsening of the environmental situation. The main cause of environmental issues are the natural and man-made geochemical anomalies caused by high content of hydrocarbon gases in the soil layer, resulting in considerable accumulation of hydrocarbon gases in some basements of residential buildings and other structures, creating hazardous situations.

The researches of gas pollution of Boryslav are conducted by a number of research teams, including IHHHK of the NAS of Ukraine, UkrDGRI, CASDZ of the Institute of Geological Sciences of Ukraine and others. Despite this, the level of gas concentration in recent years has not changed significantly. The research has shown that the major cause of gas concentration is discharge of the deep fluid systems in the permeable areas, i.e. blasted zones, which are the most active today.

According to the research of gas concentration in Boryslav performed by the experts of NIPI of UkrNafta PJSC from 2006 to 2012, it was established that the most problem gas pollution areas are located in the downtown area, near dense residential development, including outside the mining allocation (Fig. 1). The most intensive emission of hydrocarbon gases occurs in the area of Vesniana Street (City Market), Chornovola (house 10, 12, 14), Mickiewicz (house 34, 36), Hrushevskoho 1 (City Culture Department). At the same time, in the areas where the intensive exploitation of hydrocarbon is conducted, such issues are less frequent. In particular, in the area of the existing wells the hydrocarbon gas emanations are negligible. This is also confirmed by the results of aerospace surveys conducted in 2001-2002 by scientists of CASDZ V. Lalko and A. Mychak.
The research Boryslav soil contamination conducted by I. Dudok and A. Romaniuk established that the soils located near ozokerite mine in the Potik microdistrict and in the downtown area in the floodplain and bed of the river Tysmenytsia are the most polluted with petrochemicals (Fig. 1 and 2). Meanwhile it was noted that the oil content in selected samples exceeded the allowable temporary concentration (ATC - 4000 mg/kg) 2 to 8 times. In addition, the authors found that in areas with a high content of oil the increased (2-4 times compared with background values) content of heavy metals such as Cu, Zn, Co, Cd is also observed.

The situation in the field is complicated by the fact that the location of the great part of mines (unsealed pits, wells built in the late 19th and early 20th century) is unknown and is located in the area of residential development. Today some of the found wells and boreholes are not only in poor condition, polluting the environment, but also threat to the life of Boryslav residents (see Fig. 2).

Now the oil production volumes from most of the shallow wells of Boryslav deposits are minor, but Boryslavnaftogas OGPU, a structural unit of UkrNafta PJSC, is forced to continue the operation of such wells to prevent the uncontrolled outputs of reservoir and in the downtown area in the floodplain and bed of the river Tysmenytsia the are the most polluted with petrochemicals (Fig. 1 and 2). Meanwhile it was noted that the oil content in selected samples exceeded the allowable temporary concentration (ATC - 4000 mg/kg) 2 to 8 times. In addition, the authors found that in areas with a high content of oil the increased (2-4 times compared with background values) content of heavy metals such as Cu, Zn, Co, Cd is also observed.

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The extraction of hydrocarbons from Boryslav field is essential for the city, which will greatly help to reduce the level of gas concentration. This is proven by the situation with Boryslav well 494, which was drilled by shock yet in 1897 and deepened in 1905. This well is located near house 1 at Nafta Street. Due to the probable jam of the casing and folding of tubing it was decommissioned. The wellhead is equipped with a rocking machine, the electric connection of which was disconnected from the mains. On February 15, 2012 the uncontrolled release of the oil mix from the well and oil spill about the adjacent area occurred (Fig. 3, a). After oil removal the rocking machine
was dismantled and the work related to revision of the technical condition of well columns and elimination of the eventual cause of ejection was conducted. The probable cause of the oil and gas mixture release was the termination of hydrocarbons extraction from well 494 and insufficient oil extraction from adjacent wells due to freezing of exhaust lines. The committee for inquiry proposed to perform the well overhaul and transfer the same to the degasification fund subject to its connection to the vacuum line. During renovations, on July 16, 2012 the gas-oil mixture spewed from the well, resulting in contamination of the land and penetration of a small portion of the oil mixture into the unnamed stream (Fig. 3, b). In addition, due to leaks in the plumbing the petrochemicals penetrated into the Boryslav water supply system, having deprived many people of the only source of drinking water.

Another key way to minimize the level of gas pollution of the areas is the presence of two vacuum compressor stations (VCS) and vacuum pipeline network through which the mixture of hydrocarbon gas emissions is removed from the existing, inactive wells and pits. It is testified by researches carried out by us. During the period from the 12th to 14th of June 2010 we conducted sampling of gas and air mixtures in some observation spots of Boryslav field after switching off the vacuum gas collection system. During the investigated period, in degasification well 14 at 36 Danylo Galytysi Street and well 29 at 12 Chornovola St., as well as in the hole at 46 Hrushevskoho St. reached its maximum content of hydrocarbon gases starting from 2006, namely in well 14 - 31214.9 mg/m³ (during 2006-2009 - 16.873 to 11,513.04 mg/m³), the volume fraction of methane - 3.3%, in well 29 - 75861.15 mg/m³ (during 2006-2009 - 209.861 to 57,718.24 mg/m³), the volume fraction of methane - 8.67%, in hole 46 - 31819.6 mg/m³ (in 2006-2009 - 15.98 to 6447.7 mg/m³), and the volume fraction of methane - 4.7%. Based on the above, we can make assumptions about the relationship between the increasing concentrations of hydrocarbon gases in these points and VCS stop. However, the unambiguous interpretation of this phenomenon requires more prolong and thorough investigation.

As it was noted already, outside the mining allotment of Boryslav deposit there are geochemical anomalies of uncontrolled exits of reservoir fluids in the form of oil and gas to the surface in certain areas of residential development (Fig. 4).

Especially dangerous is the area around house 12 at Chornovola Street and around the ozokerite mine of the mine group (Fig. 1 and 5). Here, the Company drilled many degasification wells to reduce the gas pollution by discharge of hydrocarbon gases in the atmosphere, and we conducted the monitoring of the environment condition. During observations we repeatedly found unauthorized oil manifestation in the basement of the house and surrounding area. For example, the oil and gas mixture was released near well 25 to the surface on December 17, 2012. In our opinion, this is a testimony of the fact that these measures are insufficient, since, as it was noted already, the most effective method of gas elimination from the territories is improvement of the vacuum network for gas mixture extraction from wells and other mining wells and near-surface layers. However, according to Article 17 of the Law of Ukraine on Subsoil, "...the use of subsoil outside the mining allotment is forbidden."

There is a strange situation; on the one hand, the Company doesn’t have the moral and legal right not to deal with reduction of gas concentration, and on the other there is no legal ground for extraction of hydrocarbons outside the mining allotment.

In order to ensure the ecological balance and gradual elimination of adverse social and environmental consequences of the long-term development of Boryslav deposits, the biggest part of which is located in the city of Boryslav, Ukrnafta PJSC provides financing of the relevant programs over the past few decades. Thus, only the implementation of the Program of Urgent Measures for Prevention of Aggravation of the Environmental and Social Situation in Boryslav for 2001-2005, approved by the Cabinet of Ministers of Ukraine dd. 29.11.2001 No. 544-r, the financing of which is assumed by the state and oblast budgets and UkrNafta PJSC, the amount of funding of measures by UkrNafta PJSC totaled UAH 27.2 million at the planned UAH 26.7 million (fulfilled by 101.8%).

At the same time, the state and regional administrations fulfilled their obligations by 3.2 and 38.5%, respectively.
Since 2005 till presently the issues of gas pollution in Boryslav have been dealt by UkrNafta PJSC almost solely, while spending large amounts of money. The numerous appeals to the state government to develop the state target program to reduce the gas pollution of Boryslav found no support.

Only now the problems of Boryslav are considered at the state level. Verkhovna Rada of Ukraine passed the Law of Ukraine on the All-State Target Program of Protection of Population and Territories from Emergency Situations of Man-Made and Natural Character for the Years of 2013-2017 on June 7, 2012, which approved the program activities and the tasks to implement the All-State Target Program of Protection of Population and Territories from Emergency Situations of Man-Made and Natural Character for the Years of 2013-2017. The said law entered into force on January 01, 2013.

These measures include the elimination of the environmental and social consequences of long-term oil and wax extraction in the city of Boryslav in Lviv oblast, including the transfer of secondary school No. 7 outside the dangerous area, transfer of buildings of Boryslav Central Hospital beyond the oil and wax fields, survey of the area of oil and wax deposits in order to establish the boundaries of the territory from which the residents shall be resettled etc. The main administrator of budget funds to meet the objectives shall be the Ministry of Emergencies of Ukraine, Ministry of Energy and Coal Industry of Ukraine and Lviv Oblast State Administration.

Figure 3.3. Emergency situations which have occurred at well 494-Boryslav: a- February 15, 2012; b- July 16, 2012
It should be noted that this problem did not arise by itself. In addition to natural factors, it was reinforced by enterprises and local residents, since the decision on construction in residential houses, including the high-rise ones, in the territory of oil and gas deposits has been a gross violation of rules of the settlements development. For various reasons this trend is still present. The housing and other social infrastructure is constructed nearby and sometimes even on the oil and gas extraction facilities, which is very dangerous to humans and the environment. There are the following questions: can the permission to build housing on the wells be issued? Why is the mining allotment of oil and gas deposits constructed, etc.

Another important factor affecting the condition of gas pollution of Boryslav is the inactivity of the mine group as regards wax extraction or proper conservation of the mine. Due to the stop, the shaft tunnels got with water, which stopped their ventilation. In addition, the hydrocarbon gases are emitted due to the damage to the municipal gas pipeline network, biogas emission from the water and sewage system etc.

It is also required to pay attention to the situation with traffic in the city. In view of the fact that the bridge over the Tysmenytsya destroyed by floods in the summer of 2008 has not been repaired yet, all transit traffic is sent to the city center. Consequently, the dynamic load on the soil is increased, which leads to the formation of additional migration of hydrocarbons to the surface. In addition, the significant emission of pollutants from motor vehicles falls exactly in the epicenter of gas contamination, thereby further deteriorating the quality of life of the residents and the atmospheric air condition.

With a view to resolving the situation, according to the authors, it is required to:

1. Create a steering committee composed of the Lviv oblast state administration, local self-government, territorial bodies of the MOE, Derzhgirpromnagliad, Ministry of Environment, Ministry of Energy, UkrNafta PJSC.

2. Develop a long-term national program to eliminate the effects of long-term production of hydrocarbons in Boryslav. The program shall provide for the following measures:

   - increase in the intensity of selection of hydrocarbon from deposits in Boryslav oil field. Consider the regulatory support of drilling additional wells to extract hydrocarbons within residential developments, including the use of technologies aiming at inclined and horizontal drilling and hydraulic fracturing used in the extraction of shale gas;

   - in order to study the dynamics of change in gas concentration in time and space, conduct the aerospace research of Boryslav oil field, wax mine and adjacent areas of Boryslav deposit;
based on the research findings, create the database of the most polluted areas of the surface layers, establish the proper level of public awareness about gas pollution of the city; 
resettle the residents of individual houses from the most dangerous areas;

establish the local automated system for preventing gas explosion in the basement of residential buildings and other facilities located in the most polluted areas of Boryslav by installation of mechanical ventilation;

development and implementation of measures for decontamination of utility facilities, i.e. water and sewage, heat and other networks. Construction of new wells, repairs and maintenance of the existing system of ventilation wells; establishment of a special service for supervision of gas concentration in the city with involvement of Stebnytskyi mountain and rescue point of Ivano-Frankivsk specialized militarized mountain rescue unit for servicing of the local automated system for prevention of gas explosion in the basement of residential buildings and other facilities of Boryslav and surveillance of wax mine.

3. Develop and adopt a regulation prohibiting the construction, reconstruction, improvement and use of basements in the areas of gas pollution.

4. For degassing the surface layers, develop and take on the state level the regulatory documents which allow the extraction of hydrocarbons in the territory of polluted areas outside the mining allotment of Boryslav without special permits for subsoil plot and payment of rental. Equip the tunneling for all hazardous areas of Boryslav oilfield, mine group and surrounding areas with a vacuum network. Consider tax incentives for such businesses, or even a grant.

5. Unload the city center from the bus transportation. To do this, complete the construction of a bridge across the river of Tysmenytsia at Girna Street and arrange the bypass road for vehicles etc.

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Tendencies of Global Energy Markets

The current market of energy is peculiar of strong competition. This applies to various energies and regions of their extraction or production, as well as delivery methods. Today the most liquid markets are the markets of crude oil, petrochemicals, and coal, having global significance.

As opposed to the markets other hydrocarbons and liquefied natural gas (LNG), the markets of natural gas transported by pipelines are more isolated. The key figures of the import and export operations depend on the state of the world market of oil and its derivatives, i.e. the market of petrochemicals.

However, the European market shows a steady trend towards increasing the role of trade centers (hubs) as instruments for trade in natural gas. Three major continental centers - TTF, Gaspool, NCG - show significant growth in both trade and retail supply, which increased by almost 10%. The wholesale prices in the European hubs are equalized. At the end of 2012 the difference between the highest and lowest indices in gas prices, which will be delivered the next day (day-ahead), fell to 1 euro per MWh (about USD 14 per 1000 m³), which confirms the increasing integration of gas markets in Europe.

Historically, the natural gas in some countries, replaced the oil, leading to periodic gas indexation mechanism based on fluctuations in prices for petrochemicals used for electricity and heat production, i.e. fuel oil with low sulfur content and gas oil.

Knowledge of trends in the global markets of oil, coal and other energy, factors of influence, changes in rules and methodologies for determination of the parameters is essential for the activity of gas companies.

In February this year, along with a remarkable event in the oil market, International Petroleum Week 2013, an annual Platts London Oil Forum 2013 was held.

The leading experts made presentations in the forum and highlighted the wide range of last year's events in the markets oil, petrochemicals, natural gas, energy in general, and outlined the trends for 2013. The annual event has caused a widespread interest of the expert environment, oil and gas companies, government bodies and relevant non-governmental organizations of the European countries, USA, Russia. The representatives of the National Joint Stock Company Naftogaz of Ukraine took part in the London forum for the first time, which has enabled a deeper understanding of the nature of events and mutual influence of the markets crude oil, petrochemicals and natural gas, as well as helped improve the company's image.

The forum was attended by representatives of almost all international companies, including Total, Chevron, BP, Statoil, Shell, Eni Group, MOL, Petrobras, OMV, Hazpromeksportu.

The key reports were devoted to the growth of the US energy independence and its impact on the European market of oil and gas. The gradual transformation of the U.S. into a net exporter of oil and the increase of supply of LNG, coal and oil to the European market was noted.
Within the forum and meetings in London office of Platts the approaches and current situation with pricing in the markets of oil and gas, as well as improvement of the gas pricing indicators was discussed.

Recently, the fundamental changes in approaches to pricing for natural gas imported to European countries are observed. The new contracts on natural gas import from Norway are based on the indexation of price indices in the gas trading hubs. Still, about a half of the natural gas supply in the EU continues to be indexed by the level of prices of oil products.

The modern condition of the international energy markets requires thorough daily study, analysis, monitoring of performance, characteristics and development trends, which will directly contribute to increased efficiency of business of oil and gas companies.

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