Oil & gas industry of Ukraine

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Prospect for oil and gas bearing capacity in Ukrainian sector of the Sea of Azov by a comprehensive assessment of GPS study data

Yevdoshchuk M.I., Halko T.M., Sedlerova O.V., Volkov A.V., Yakubenko G.M.

Simulation of filter gravel pack in-wash in a well with a significant deviation from a vertical or in horizontal well

E. H. Striukov

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Some ways to improve construction technologies for shale gas wells

Mysliuk M. A., Khominets Z.D., Salyzhyn Yu., Bohoslavets V.V., Voloshyn Yu.D.

SEFDR Nezalezhnist started to work in the Black Sea

The Nezalezhnist self-elevating floating drilling rig (SEFDR) started drilling its first well in the Black Sea on February 01, 2013. These works are performed in Arkhangelsk gas field within the scope of the production plan of Chornomornaftogaz for 2013, which foresees a 40 % increase in production in the area of Black and Azov Sea shelves – from 1,17 to 1,65 billion m3 of natural gas.

With the support of Naftogaz of Ukraine, the Chornomornaftogaz PJSC is performing a large-scale production upgrade, which will give the company an opportunity to reach an output rate of 5 m3 of natural gas starting in 2013, and to triple its annual gas production and open several new hydrocarbon fields during next three years. The Nezalezhnist self-elevating floating drilling rig which is provided with modern equipment and, along with Petro Hodovanets SEFDR, is one of the most hi-tech and high-capacity SEFDR in the Black Sea region. It has been designed and constructed in Singapore shipyard Keppel FELS in 2012. Nezalezhnist possesses the best characteristics: both the depth of water (up to 120 m) and drilling depth (9144 m), it is capable of drilling 12 wells in one position. Its drilling quality meets the standards of the American Petroleum Institute (API), it is also compliant with the requirements concerning labor protection, sanitary and ecological requirements set by Ukrainian and international regulations. The Institute of Engineers Singapore (IES) has declared the Nezalezhnist SEFDR (KFELS B Class project) to be the most environmental-friendly in the world. The SEFDR is capable to function during storms with wave height up to 15 m and wind speed up to 130 km/h.
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The magazine “Oil and Gas Industry” has ceased to exist in 2013 due to change of its founder, and a new science and production magazine called “Oil and Gas Industry of Ukraine” has been registered at the Ministry of Justice of Ukraine (Certificate of State Registration of a printed media Series KВ No. 19813-9613P dated 09.04.2013). The competence of this magazine is confirmed by the reputation of the national public joint-stock company, as a leading enterprise of the fuel and energy sector of Ukraine. This periodical will preserve and continue traditions of “Oil and Gas Industry” that are more than 50 years old by publishing articles that cover a large spectrum of actual issues of the oil and gas industry in the fields of economy, geology of oil and gas, well drilling, production, storage and processing of oil and gas, automation and informational technologies, and also labor and environmental protection.

The index, publishing schedule and requirements for published articles in the “Oil and Gas Industry of Ukraine” are the same as those of its predecessor. The magazine will be published in Ukrainian, but some articles will be also published in English.

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OIL AND GAS GEOLOGY

Oil and gas potential of Ukrainian sector of the Sea of Azov by a comprehensive assessment of aerospace research data

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One of the lines of optimization of prediction and exploration of oil and gas fields in the offshore area is involvement of new unconventional data sources, in particular materials of multispectral satellite imagery. A rating assessment of oil-and-gas promising areas in the Ukrainian sector of the Sea of Azov was carried out, taking into account the results obtained in determining the rank of OGPA according to the structural and geomorphological, neotectonic, spectral and brightness, and structural and geological criteria.

In 1976 a gas spouter was obtained in the area of the Sea of Azov at the Pivnichnokerchenskaya structure. From now on a significant part of scientists and producers research for the oil and gas potential and directions of further works in the area of the Sea of Azov [1].

In 1998 after the long break the well No. 1 was drilled at the Pivnichnokazantypskaya structure and the gas field Pivnichnokazantypskoye was opened, which was related to the upper part of the Maikopian sediments. In 1999 Skhidnokazantupskoye gas field was opened in Neocomian sediments of upper Miocene, and in 2000 Pivnichnobulganatske gas field was opened, which was connected with carbonate formations of Badenian strata. Recently there was supplementary exploration of Pivnichnokerchenskoye gas field in Badenian sediments.

So, the expectations are rewarded with positive results and discovering of the fields in case of geological exploration (GE) growth and complex approach to the study of predicting, perspective and prepared sites. The relevance of comprehensive assessment of oil and gas potential areas, sectors, sites, objects according to all possible methods remains high. It includes also the application of complex prediction method of oil and gas potential objects using data of Earth remote sensing (ERS) in the assessment of chosen areas.

One of the lines of optimization of prediction and exploration of oil and gas fields in the offshore area is an involvement of new unconventional data sources, in particular materials of multispectral satellite imagery. Unlike the traditional complex of geological and geophysical exploration based on method of "multi-stage generalization" (a generalization of data obtained in different areas), aerospacegeological studies (ASGS) help to obtain a complete picture of the structure of large-sized elements of the earth's surface on space images (SI) with further specification of individual sections on materials of aerial survey or SI with high resolution.

Use of aerospace information provides the update of geological structure of oil and gas potential areas, study and tracing of various structural forms, which may be associated with oil
and gas fields, identification and prediction of new potential objects for goal-oriented setting of oil and gas exploration activities. The unified complex of low-cost methods is appropriate at all stages of hydrocarbon (HC) search: predictive, prospecting, reconnaissance [2], which increases the efficiency of oil and gas potential of the Ukrainian sector of the Azov and the Black Sea waters of Ukraine.

The theoretical basis for data use of remote shooting for the study of oil and gas potential areas both onshore and offshore is the concept of information transfer about the underlying structure of the Earth's surface (bottom surface). This transfer can be carried out both during the mechanical displacements and foundation block vibrations and deformations of sedimentation mass, and through the geochemical transformations of the individual components of the landscape under the influence of deep fluids [3]. The distinctive features of deep structure also appear in geophysical fields (electromagnetic, gravitational, thermal, etc.), and hydrodynamic regime and the stress-deformed state of the rocks, as well as in a variety of landscape indicators that are fixed on the distance shooting materials.

On the basis of the analysis of previous studies in shelf zones [4] and based on experience of the activities performed in CASRE for the period from 1992 to 2012 [3, 5, 6] the conclusions about various forms of geological bodies and processes in the bottom landscapes, as well as in the water column and on the sea surface are made.

First of all, it should be noted that a significant part of indicators peculiar to the land can be used to decrypt the submarine relief. Thus, the reconstruction of an ancient drainage system allows to identify a number of patterns peculiar to neotectonic uplift and disjunctive dislocations. Large morphostructures are allocated by direct occurrence on relief. The uplifts, deeps, sharp bends at the bottom are fixed clearly enough by the change of the picture and the density of fractures (lineaments). Massive disjunctive dislocations may correspond to horst- and graben-like deformation of the bottom, raising uplifts and stretched along one axis uplift chains (both modern and ancient), various abnormalities in the structure of underwater landscapes, which occur along certain lines, etc. Grouping of bottom gas occurrence indicates the geological dislocation.

In order to assess neotectonic activity of selected local morphological abnormalities we performed structural and geomorphological studies: we built maps of vertical and horizontal compartmentalization and determined the amplitude of current tectonic movements.

As a result of joint analysis of ERS data and structural and geomorphological analysis in the water areas 6 areas of anomaly concentration were identified from these data (Figure): 1 - Chynhulska, 2 - Oktjabrsko-Morske-1-Obruchevska (subzone: 2a - Oktjabrsko-Morske and 2b - Obruchevska), 3 - Litolohichna, 4 - Mysova-1-Pivnichnokerchenska, 5 - Pivdennoberdyansko- Olimpijska, 6 - Strilka. The territorial concentration fields of HC, oil and gas potential objects (OGPO) and prediction and prospective objects (PPO), the impact of regional and local tectonic disturbances on their allocation were analyzed separately. Each selected area is a zone of territorial concentration fields of HC, OGPO and PPO, as well as the area of anomaly concentration detected by the remote data and during structural and geomorphological studies.

Oil and gas potential objects (OGPO) were selected for local analysis, which are the part of the fund structure of the State Geological Survey of Ukraine as of 01.01.2012: structures prepared for deep drilling (2 - Pivnichnobrairyucha, 3 - Shidnobairyucha, 4 - Obytichna-1, 5 - Obytichna-2) and and detected by seismic survey (6 - Tsentralna, 8 - Blokova, 9 - Heofizychna, 10 - Pivdennoberdyanska, 12 - Bilosarajska, 13 - Udarna, 14 - Olimpijska, 17 - Obruchyeva-2, 18 - Obruchyeva-3, 22 - Morska, 26 - Litolohichna, 29 - Zahidnobulhanatska, 32 - Mysova-1, 34 - Sonyachna, 35 - Kytenska) (See Figure).

It was necessary to determine by rating assessment the priority of oil and gas potential objects that are prepared for drilling and are detected by seismic survey in order to obtain
conclusions and recommendations for further geological exploration for oil and gas in the Ukrainian sector of the Sea of Azov.

For calculating the coefficients of the drilling priority ($K_{ge}$) or preparations for it the most accurate parameters that are closely related to the results of the seismic survey were used: area ($K_a$) and type of trap ($K_{tt}$), the depth of predictive productive horizons ($K_h$), and also drilling, category $C_3$ resources or $D_{1,lok}$ ($K_P$), the degree of oil and gas potential depth ($K_{ogpd}$). The accuracy of determination of the last two depends largely on the waters of drilling scrutiny.

Evaluation system for each oil and gas potential object was chosen so that the maximum numerical value of the coefficient sequence corresponds to the most effective indicator achieved after positive results of drilling (open field) and its further exploration.

The integrated index of drilling priority or preparations for it - $K_{ge}$ (rating assessment) of OGPO of Ukrainian sector of the Sea of Azov is calculated by multiplying the above five coefficients [7, 8]:

$$K_{ge} = K_a \cdot K_h \cdot K_{tt} \cdot K_P \cdot K_{ogpd}$$

The top-priority objects are considered the objects with $K_{ge}$ more than 0.4. These are the structures, which by the above criteria can be recommended for introduction in drilling or preparation in the first place. The objects with second priority with $K_{ge}$ 0.3–0.4 are the structures, the search results of which are estimated to be less effective than the top-priority structures. The structures with third priority with $K_{ge}$ less than 0.3 are the structures that should be avoided from the introduction of exploratory drilling and seismic survey.

Four objects prepared for exploration drilling in the Ukrainian sector of the Sea of Azov (Pivnichnobiryucha, Shidnobiryucha, Obytichna-1, Obytichna-2) are located only at the Chynhulskiy saddle of Eastern European Platform (EEP) and don't solve problems and prospects of oil and gas potential of the sector as a whole. The integrated index of priority drilling or preparing for it, $K_{ge}$, was determined in the range 0.308 – 0.4 for these structures (according to some data 0.495) that corresponds to the II range of the objects.

Among identified oil and gas potential objects five of them (Obruchyeva-2, Litolohichna, Sonyachna, Zahidnobulhanatska, Mysova-1) have a rank I that corresponds to the structure assessment that by the above criteria can be recommended for introduction in drilling or preparation first.
Seven more identified structures (Morska, Obruchyeva-3, Kytenska, Pivdennoberdyanska, Bilosaraaska, Udarina, Olmijska) have rank II. Possible results of these structures are estimated to be less effective than the structure of the first stage.

Three identified patterns, Centralna, Blockova-3 and Geofizychna, obtained the III rank with coefficients $K_{ge}$ from 0.134 to 0.277.
In a similar way it was calculated the priority coefficient by criteria complex of Earth remote sensing: an integrated spectral coefficient (Ksc), complicated object with lineament zones (Kl) and area concentration of structural and geomorphological anomalies (SGA): display of structured in relief of the seabed (Kr), neotectonic activity (Kna), the coefficient of horizontal compartmentalization (Kh), the coefficient of vertical compartmentalization (Kv), the heredity of the structure (Khs).

Obtained as the product of these seven coefficients an integral coefficient Kers allows to divide 4 prepared and 15 identified structures into three groups, defining a certain rank for each. The top priority targets are considered objects with Kers more than 0.5. Objects of the second stage are with Kres 0.4-0.5. The structures of third stage are with Kers less than 0.4.

So, we have identified the most perspective structures of I rank: among prepared is Obytichna-1, among detected - Litolohichna, Obruchyeva-3 Bilosaraisha, Pivdenno-Berdyanska.

Objects with fewer potential (II rank): among prepared are Pivnichnobiryucha, Shidnobiryucha, Obytichna-2, among detected are Morska, Obruchyeva-2, Olimpijska, Udarna, Zahidnobulhanatska, Sonyachna, Mysova-1, Kytsenska.

The least prospective objects can be considered the objects of III rank. These are detected structure Centralna, Blokova-3, Geofizychna.

The accuracy of calculation parameters for objects of Cretaceous and Cenozoic of Pivnichnoazovskiy, Indolo-Kubanskij basin and Azov shaft is different because of insufficient knowledge of the Sea of Azov by modern seismic survey by method of joint depth point (MJDP) and drilling. Therefore, the obtained results can be a powerful argument during the selection of top-priority sites considering the new geological and geophysical results and other geological studies.

The uncertainty of the boundaries between tectonic elements from south to north in the Ukrainian sector of the Sea of Azov, the lack of factual material on deep seismic horizons and their stratigraphic relation, the ascertaining of the influence of tectonics of lithospheric plates, and thus, oil and gas geological zoning requires clarification of oil and gas potential of the territory by providing regional seismic studies, direct and unconventional methods of searching HC, Earth remote sensing.

Rating assessment of oil and gas potential objects was carried on the basis of five oil and gas geological criteria (Kge) and seven criteria of ERS and structural geomorphological abnormalities SGA (Kers) and it showed that the obtained results are somewhat divergent, particularly in relation to the objects of the first rank.

Thus, carrying out of rating assessment (table) is offered with regard to the weight of structural and tectonic elements (Kste), basic oil and gas geological elements (Kogge) and calculated density of undiscovered resources of HC (Kd) with integrated index of priority drilling or preparing for it (Kge) and the weight coefficient (Kers). Integral coefficient is defined as the product:

\[ K_I = K_{STE} \cdot K_{OGGE} \cdot K_D \cdot K_{GE} \cdot K_{ERS}. \]

Therefore, based on the extracted integral coefficient (Ki) the priority objects are specified and objects of the second and third rank are identified (see Table).

Results of data interpretation have shown that among four prepared objects for deep drilling located on Chynhulsiky saddle, EEP, it is recommended to set parametric drilling for structure of the II rank Obytichna-1. Because of negative result at the well 1-Zahidnobiryucha objects Obytichna-2, Pivnichnobiryucha and Shidnobiryucha should remain in reserve until the results of the parametric drilling at the well 1-Obytichna.

Identified structures (objects) of I rank require formulation of detailed seismic survey by
MJDP (Morska, Kytenska) detailed seismic survey by MJDP and exploratory drilling (Zahidnobilhanatska and Mysova-1).

Identified structures of II rank are based on geological and geophysical data and evaluation according to ERS data that are recommended for parametric drilling (Litologicchna and Pivdennoberdyanska); for search and detailed seismic survey by MJDP (Obruchyeva-2 and Obruchyeva-3); for detailed seismic survey by MJDP exploratory drilling (Sonyachna); for search and detailed seismic survey by MJDP and parametric drilling (Bilosaraitska).

Rank III includes Centralna, Blokova-3, Geofizychna, Udarna, Olimpijska structures because they are in the reserve, it is recommended to perform detailed activities and alternative methods of hydrocarbons search, primarily aerospace, structural and geomorphological research.

Specialists of SE «Naukanaftogaz» [9] carried out a rating assessment of objects of the Sea of Azov, Prikerchenskyj and north-western Black Sea shelf which are prepared for drilling. As a basis of determining the parameters of a rating assessment in this publication three groups of factors has been selected: search, exploration and economics. According to the experts [9] the prepared structures within the Azov shelf have the lowest ratings, in particular, the coefficient of success and zonal coefficient are the smallest, and the performance of chalk sediments, which are prospective for these two structures (meaning prepared for exploratory drilling of Pivnichnobiryucha and Shidnobiryucha structures - auth.) within the Ukrainian sector of Azov shelf yet to be established [9].

Rating evaluation and recommendations concerning oil and gas potential objects (OGPO), prepared and identified (prospective), of the Ukrainian sector of the Sea of Azov including the materials of ERS [1] with updates as amended as of 01.01.2012
<table>
<thead>
<tr>
<th>No. of</th>
<th>Object</th>
<th>Rating</th>
<th>Importance of Oil and Gas Potential Objects (OGPO)</th>
<th>Importance of Major Structural and Tectonic Elements of the Ukrainian Sector of the Sea of Azov</th>
<th>Importance of Basic Oil and Gas Geological Elements</th>
<th>Coefficients</th>
<th>Importance of Rating Assessment OGPO According to GE</th>
<th>Importance of Rating Assessment OGPO According to KR</th>
<th>Integral Indicator of Priority (Ranking Score) of OGPO of Ukrainian Sector of the Sea of Azov</th>
<th>Object Rating (Structures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pinichnobiryucha</td>
<td>0.8 (Chyn. s.)</td>
<td>0.8</td>
<td>Biruch-Zahidnoazovska area of predictive oil and gas accumulation</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.466</td>
<td>III</td>
<td>reserve</td>
</tr>
<tr>
<td>4</td>
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<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>1.0</td>
<td>0.576</td>
<td>II</td>
<td>parametric drilling</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Obytichna-2</td>
<td>0.8 (Chyn. s.)</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.466</td>
<td>III</td>
<td>reserve</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>Centralna</td>
<td>0.8 (Chyn. s.)</td>
<td>0.8</td>
<td>B-ZA pr. o/g/a</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.368</td>
<td>III</td>
<td>reserve</td>
</tr>
<tr>
<td>8</td>
<td>Blokova-3</td>
<td>0.8 (PAD)</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.368</td>
<td>III</td>
<td>reserve</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Geoifizychna</td>
<td>0.8 (PAD)</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.368</td>
<td>III</td>
<td>reserve</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pivdennoberdyanska</td>
<td>0.8 (PAD)</td>
<td>0.8</td>
<td>0.9</td>
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<td>I</td>
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Notes:
1. Tectonic elements (abbreviation): Chyn. s. – Chynhulska saddle, Pivdennosvasko-Tymashivskyj downfold, AS - Azov shaft (Serodnoazovskie uplift), Tim. d. - Tymashivska degree, IKB - Indolo-Kubanska basin;
2. Oil and gas geological elements (abbreviation): B-ZA pr. o/g/a - Biruch-Zahidnoazovska area of predictive oil and gas accumulation; PdSyv-Tim. p (g-b) r - Pivdennosvosko-Tymashivskyj perspective (gas-bearing) region; TT-PnK ogr - Tamansko-Temryutsko-Pivdennokorenskij oil and gas region.
Two more structures prepared for exploratory drilling were not even considered in the article [9]: Obytichna-1 and Obytichna-2. These categorical and disappointing findings reaffirm the need for more detailed and comprehensive approach to the preparation of objects for drilling, the involvement of obtained research results from using both geological and geophysical, as well as aerospace methods.

From all described above the following conclusions can be made.

The uncertainty of the boundaries between tectonic elements from south to north in the Ukrainian sector of the Sea of Azov, the lack of deep factual material on seismic horizons and their stratigraphic relation, the ascertainment of the influence of tectonics and geological fluid dynamics, and hence oil and gas zoning requires the use of unconventional methods of searching HC and methods of ERS.

A rating assessment of oil and gas objects was provided, taking into account the data obtained during the determination of rank OGPO by structural and geomorphological, tectonic, structural and geological criteria and spectral brightness criteria. The obtained results make it possible to determine the ranking of prepared for deep drilling and seismic detected (prospective) structures.

Significant prospects of oil and gas potential areas of the Sea of Azov are established, Morska, Kytenska, Zahidnobulhanatska and Mysova-1 are defined as top priority structures, all four are at the fund of structures on 01.01.2012 listed as detected, and have the lowest rank. Among the prepared structures, only one (Obytichna-1) got a second rank.

References


NEWS

The negotiations on gas supplies from Russia to China

OJSC "Gazprom" and the Chinese National Petroleum Company agreed till the end of the year to finish negotiations on gas supplies to China. Russian gas export will be 38 billion m$^3$ per year. There are also significant opportunities for future supplies of liquefied natural gas from Russia to China.

OJSC "Gazprom" does not exclude the possibility of building a gas pipeline from Russia's Altai region to the western regions of China, which can supply an additional 32 billion m$^3$ of gas per year. The development of shale gas export from the United States urges Russia to seek out new consumers of natural gas.

Pipeline & Gas Journal / April 2013, p. 14

Pakistan plans to import gas from Iran

Pakistan continues to build a gas pipeline to supply gas from Iran. The question is whether Pakistan is able to finance the construction of the pipeline worth $1.5 billion. Iran plans to finance the construction of 560 miles of pipeline, including 200 miles of its territory. The segment of Pakistan is 500 miles. The gas supply would begin by the end of 2014.

As you know, the United States supports an alternative pipeline project - from gas fields in Turkmenistan to Afghanistan, Pakistan and India.

Pipeline & Gas Journal / April 2013, p. 14

WELL DRILLING

Some aspects of operational reliability of the drill string and its components in well construction process

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The paper considers operational efficiency of the well deepening procedure based on the probable drilling performance and the state of drill string components. The results of the pilot drilling are shown with a record of vibrations, which are used to determine the normal operating conditions of the drill string and its components.

Among the reasons of short operating lifetime of the drill string elements, especially, rock cutting tools, we can distinguish the specific nature of the process of oil and gas wells drilling. Therefore the elements of a drill string must possess high reliability and optimal longevity. Each additional round-trip operation is associated with economic costs. Thus, increase in feed range and increase or maintenance of the mechanical speed gives an opportunity to lower economic expenses for hole making. Improvement of boring head performance characteristics depends not only on the improvement of its construction but also on lowering of solid phase content in washing fluid and choice of its optimal density. The probability of no-failure operation of the drill string is closely related to consideration of its endurance under the influence of static and dynamic load during interaction between a drilling bit and rock with hole.

The defining safety criterion for technological safety of a drill string is its reliability
during hole making in certain geological and technical conditions, which is also one of the basic quality indexes of every construction (mechanical system). It’s reliability of the drill string which allows performing of given functions, deepening of a well and preserving of its operating characteristics of a during well construction.

A drill string consists of a number of sections that construct a consistent mechanical system built of drill pipes and drill collars, with a lower part consisting of a rock cutting element, a bagging attachment and bearing structures. The upper part contains a rotor, its transmission, a hoisting tackle (suspender) and moving masses: a hanger, a swivel neck and moving blocks.

We should note that the problem of the reliability of a drill string and its elements has been considered only in terms of formation of regulatory characteristics of its construction defined by its end operational criteria and quantitative assessment of such characteristics defined by given constructional and technological characteristics, including drilling output parameters. In this case statistical probability theory has been chosen as analytic algorithm, which uses retrospective data on performance of drilling bits and other elements of a drill string in various geological and technical conditions as its database.

![Fig. 1. Oscillograms of change in frictional force over time corresponding to different values of $\mu = (P)$: $a$ – normal operating mode; $\delta$ – first-order brace; $\vartheta$ – second-order brace](image1)

![Fig. 2. Dependence curve of friction coefficient and normal load.](image2)
Fig. 3. Oscillograms of change of dynamical characteristics of the upper part of a drill string during drill by A9Sh. turbodrill (hole depth 1200 m, \( P_\text{max} = 150 \text{ kN} \)): \( a \) – 0–30 Hz; \( \delta \) – 30–70 Hz; \( \varepsilon \) – 70–80 Hz

Fig. 4. Dependence curve between friction coefficient and sliding velocity

The main source of information that allows estimation of reliability of drill string elements during well drilling is statistical data for wear of drilling bits, holereamers, threaded connections and other drill string elements, and also failures due to other geological and technical reasons. It also serves as a feedback about the conditions of drill string elements and gives the idea about the extent of reliability provided by working parameters, drilling type and conditions of well washing. In this methodological setting, reliability of drill string elements is a weakly controlled category, this also applies to other pipeline systems [1]. It’s important to mention that further calculation of reliability parameters will be based on implementation of a system approach to the problem based on a complex solution for the tasks of reliability of drill string elements and, first of all, of the rock cutting tool – drilling bit, which is vital for increase in drilling performance and decrease in failure rate.

To provide a fair assessment of functioning of a technological process of well deepening and construction, we use drilling parameters, which ensures performance of basic process reliability criteria:

probability of obtaining drilling parameters compliant with geological and technical work order (GTWO) \( F_\text{c}(t) \);
probability of performance of the task during one headway $F_t(t)$; costs of round-trip operations (RTO) and other auxiliary operations according to the standards $C_{\text{op}}$;

efficiency rate calculated by mechanical drilling speed:
\[ V = \frac{v}{v_{\text{me}}}, \]

where $v_{\text{GTWO}}$, $v_{\text{факт}}$ – are standard and factual levels of mechanical speed for a certain geological section respectively;

Efficiency coefficient of a feed range:
\[ Y = \frac{h_{\text{GTWO}}}{h_{\text{факт}}}, \]

where $h_{\text{GTWO}}$, $h_{\text{факт}}$ – are standard and factual feed range.

The definition of $F_k(t)$ and $F_t(t)$ criteria requires special research that characterizes reliability of additional works related to RTO, drilling bit replacement, composition of the lower part of a drill string, etc.

Basic features that characterize reliability of a technological process of well construction and require maintenance of its reliability (reliability in terms of construction) – it’s reliability in terms of endurance capacity and wear of separate units and elements of a drill string; boundary state of drill string elements when values of some parameters of well deepening are not within the range of defined requirements; state of a drill string and a technological process of drilling; drilling failure which is defined as troubles with its production capacity due to technological reasons or a breakdown. All these terms are related to geological and technical conditions of drilling.

Not only geometrical characteristics of drill string elements change during the course of drilling: their structure, their properties and state of stress change, too. These changes may be monotonous or pronounced. At first it applies to the bearing of roller cone bits, especially with ball bearings. The nature of changes in the rolling contact bearings to some extent depends on type of friction, conditions of mechanical load, washing fluid formulation, solid phase content in the fluid and properties of the material of the details and on physical-mechanical properties of rock that is drilled out.

Quantitative and qualitative research of wear of roller cone bit during drilling in different geological conditions have demonstrated that the intensity of bearing structures destruction is determined by three factors: exterior dynamical influence of drill string under dynamic excitation, of drilled rock, and of exterior environment and properties of surface layers and resulting material friction. We can imagine a drilling bit as a combination of kinematic pairs of friction influenced by dynamic load. Load condition of the drilling load is characterized by a defined load range. Such nonstationarity of a drilling bit load can be explained with two following reasons:

- stepping nature of load during advance of tool and smoothness of its implementation between two advances;
- various oscillating processes of a drilling tool.

In this case, the main factors that determine the progress of the friction and wear of the material in the kinematic pairs are external kinematic effects, atmospheric pressure, relative sliding speed, etc.

Dynamic effects on kinematic pairs of a drilling bit are defined by drilling modes, and the intensity of these effects, in turn, is defined by linking of the bottom of the drill string and
mechanical properties of rocks that are drilled out. At the same rotational speed determines the speed of sliding velocity: its increase leads to more extensive destruction of surfaces.

The authors of one research [2] conclude that frictional forces are not a function of normal load $P$, but a function of processes that emerge as the result of different combination of the normal load $P$, sliding velocity $\omega$

and friction parameters vector $\bar{C}$ (materials, environmental conditions, etc.). In general, the friction force and the normal load, under condition of mechanical, thermal and material contact of surfaces of friction and the environment are linked to some operator $\omega$:

$$T(P) = \omega(P, n, \Gamma_{\text{um}}, \bar{C}).$$  \hspace{1cm} (1)

The aforementioned can be summarized as follows: the friction force is not a function of the axial load (of stretching in case of its upper part), but of the processes that occur as the result of each combination – rotational speed of the drilling bit during drilling by a drive-out motor or of a rotor (rotating the entire drill string), conditions of washing of wells, geological and technical conditions of drilling. All this affects the operation of the mechanical system of the drill string. In this case, the friction force may vary over a wide range - depending on the flow of the leading process. We write the relationship for the friction force in the parameters of well drilling:

$$T(P) = \omega(P, v, \bar{C}).$$ \hspace{1cm} (2)

where $P_{\text{oc}}$ – is axial load on the drilling bit; $n$ — rotational frequency of the drilling bit; $\Gamma_{\text{um}}$ – geological and technical conditions; $C$ – influence of the washing fluid, its abrasiveness etc.

We use the “weak link model” [3], which is a system of series-connected elements (drill pipes, drill collars drilling bits etc.). In this model, in case of failure of one element (mostly – of a drilling bit), the whole link collapses, thus leading to the necessity of pulling-out of string drill in order to replace the bit (no drilling process). This makes it possible to consider the reliability of the bit separately, but with due consideration of the impact of the dynamics of the drill string on the drilling bit. Considering the fact that a drilling bit usually operates in abrasive environments, it is necessary to pay attention to the failure due to abrasive wear of its rolling contact bearing. Abrasive wear and damage is a process of destruction of the main parts of bearings and bearing structures due to abrasive environment in friction zones.

The presence of abrasive in the contact zone leads to a significant local concentration of stress during plastic deformation. Plastic deformation increases with decrease of size of solid abrasive particles, and with the increase of variable loads. To a lesser extent, the process of abrasion is accompanied by microcutting leading to chips formation.

Normal mechanical functioning in case of rolling friction depends on the normal load and relative movement. When certain normal pressure values are achieved, damage from wearing starts to develop. Further increase of load leads to mashing with microdamage of the contact surface. It is important to note that abrasive particles present in washing fluid may be both pointed and have round grain shape. The advantage of each type depends on physical and mechanical properties of the rock that is drilled out, on a drilling mode and on the level of cleaning of the hole.
Fig. 5. Oscillograms of variation of friction over time obtained at various sliding speeds \( \mu = f(t) \): \( a \) – stationary section; \( \delta \) – second-order brace; \( \varnothing \) – first-order brace

Fig. 6. Vibrorecord of change of dynamical characteristics of the upper part of a drill string during drill by A9Sh. turbodrill (hole depth 1200 m, \( P_{\omega} = 150 \text{kN} \)): \( a \) – 0–30 Hz; \( \delta \) – 30–70 Hz; \( \varnothing \) – 70–ВК Hz

Fig. 7. Caliper measurement and diagram of vibration velocity level
The friction theory [4] is not applicable in our case due to the following reasons: there are difficulties in direct observation of functioning of bearing structures; nontriviality of the mode of deformation scheme and destruction mechanisms; thermodynamic imbalance of surface layers under load; influence of washing fluid which contains abrasive solid phase and chemicals; drilling bit functioning is connected with anisotrophy and alternation of rocks that are drilled out.

Let’s consider the results of the experiments in order to solve the question of friction quotient behavior.

One research paper [2] provides data obtained during experimental study of relationship between the change in friction coefficient and normal load $\mu = \varphi(P)$. This dependence has three characteristic sections: I – stationary corresponding to normal mode of working; II – transitional; III – with damage mode. Oscillograms (Fig. 1) obtained during this research [2], and a curve of change in friction coefficient (Fig. 2) are given below. Fig. 3 shows oscillograms of vibrations of the upper part of a drill string, recorded with the help of bandpass filters with the frequency range from 0 to over 70 Hz.

The normal mode is defined by a stable and persistent coefficient of friction. It also applies to vibration velocity. The limits of the normal working mode are determined by critical pressure $P_{cr}$ which is a function of an axial load $P_{ax}$. Exceeding $P_{cr}$ leads to binding of pathological processes of various intensities (see Fig. 2, section III). Thus intensive fluctuations of frictional forces (see Fig. 1, $v$) and vibration velocity occur (see Fig. 3), leading to intensive wearing and, as the result, to emergency situations. Changes in both oscillograms are logical.

The dependence of change of the frictional coefficient on velocity of sliding of inner frictional pairs in a drilling bit also has three sections (Fig. 4): I – pathological, due to drilling bit breaking ($0 < \omega < \omega_{cr}$); II – normal mode ($\omega_{cr} < \omega < \omega_{''cr}$); III – pathological processes emerging due to second-order brace ($\omega \geq \omega_{''cr}$). The normal mode section with stable value of friction coefficient and permissible wear lays between sliding velocities $\omega_{cr} \leq \omega \leq \omega_{''cr}$.

In case of normal drilling bit functioning the friction coefficient is determined by friction parameters, materials and their processing procedures, size of bonds, and by type and properties of oiling.

The complex influence of these parameters leads to change in $\mu = \varphi(P)$; $\mu = f(\omega)$ function values. That is to say that change, in drilling bit state leads to change in vibrational state of the drill string. Change in axial load or rotation frequency of the drilling bit causes the change in friction force in inner kinematic pairs of the drilling bit, which, in its turn, leads to change in vibrational state of the drill string.

To provide plausible interpretation of the similarity between the oscillograms of the friction force over time (Fig. 5) and sliding velocities, that corresponds to the relation $\mu = f(\omega)$, we provide vibrorecords for a tricone drill bit performance during the course of one drill (Fig. 6).
It's obvious that these oscillograms are very similar and can be used during of control of drilling performed by roller cone bits, at the same time the necessity to consider dependency of the vibration velocity on rock hardness occurs (Fig. 7).

We know [4], that signal frequency range on the surface amounts to 0,5 to 500 Hz and more. This range can be divided into four subranges: I – from 0,5 to 30–40 Hz – is characterized by wave character of drilling, transverse vibrations of drill string elements that are transformed into longitudinal vibrations of a rotary swivel;

II – from 40 to 250–300 Hz – is characterized by relative rock hardness and wear of drilling bit equipment; III – from 300 to 500 Hz – characterizes rolling contact bearing performance; IV – exceeding 500 Hz – hydrodynamic noises occur, interaction of drill string elements with the walls of the well. The intervals of such frequency subranges will depend on drilling mode and on type of engine and drilling bit applied during the course of drilling.

During experimental researches at drilling stations in Prykarpattia region rates of vibration and mechanical speed of headway have been obtained. It has been demonstrated that, when roller cutter drilling tool is used, dynamical load of drilling primarily influences on and deforms bearing structures which is facilitated by friction and performance in abrasive environment, which is, in its turn, related to physical and chemical properties of drilled rock. Soft rock drilling is characterized by more intense approximation of surfaces of the drilling bit and the well thus leading to increase in friction force and vibration amplitude of the drilling bit at low frequencies. When hardening of rock vibration amplitude decreases and low-frequency vibration rate increases leading to decrease in friction coefficient. This conclusion is made for a fixed arrangement of the drill string bottom and constant drilling modes. Dependency of mechanical speed and vibration rate on headway is represented in the Fig. 8. There is a correlation between the mentioned dependencies.

The results of experimental studies demonstrate that for drilling of homogenous rock with the use of similar composition of the lower part of a drill string and stable drilling modes for a certain drilling bit construction, friction forces remain stable on condition that there is no axial play in rolling cutters.

The analysis of changes in vibration velocity at frequency ranges mentioned above, can serve as a diagnostic factor in determining drilling bit bearing status during the drilling, of its lifetime and reliability in specific geological and technical conditions. Further development of diagnostic methods is related to the study of the wear of drilling bit bearing and of the impact not only of operational parameters of drilling, but also of dynamics of the construction of the drill string in specific geological and technical conditions. The following factors also play an important role in the wear of the bearing: well washing mode, washing fluid formulation, development of special complex equipment.

References
NEWS

Gazprom gives green light to a liquefaction plant in Vladivostok

The management of Gazprom JSC has approved the investment proposal for the construction of a liquefaction plant near Vladivostok. The plant will have three production lines, each with an annual capacity of 5 million tonnes of liquefied natural gas. It is expected that the first phase of the plant will be commissioned in 2018. Gas will be delivered from Sakhalin offshore fields, as well as from Yakutia and Irkutsk region. This gas will be sold in the Asia-Pacific region.

Pipeline & Gas Journal / April 2013, p. 4

New large gas field in Qatar

According to the official sources of Qatar, a new gas field has been discovered after intensive exploration over the last four years, including the drilling of two exploration wells within the block - 4N. Qatari partners Wintershall and Mitsui were partners of Qatar Petroleum.

Initial gas reserves at the field are estimated at 140 billion m³.

Pipeline & Gas Journal / April 2013, p. 14

Japan starts extracting methane from gas hydrate deposits

According to a report from Japan, gas production from offshore deposits of methane hydrates started last month, which, according to leading experts, can lead to the development of this promising energy source. It is believed that extracting gas from marine gas hydrates has been performed here for the first time in the world. Experts estimate that carbon content in gas hydrates is at least twice that of all other fossil fuels in total.

Pipeline & Gas Journal / April 2013, p. 14

OIL AND GAS PRODUCTION

Simulation of filter gravel pack in-wash in a well with a significant deviation from a vertical or in horizontal well

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УДК 622.276

Swirling flow simulation problem is used to develop algorithms for structural optimization of swirlers designed for installation of a gravel filter in horizontal or controlled directional wells. The practical need for study of hydrodynamic processes for circular channels encourages the use of numerical calculations for a set of basic models with a different simplification degree. The paper presents the relevant models and design data.

Mathematical modeling of swirling flows is one of the most important tools of research. This allows in many cases to reproduce a detailed picture of the studied currents, calculate the main characteristics of the flow.

Hydrodynamics in a horizontal borehole of the well is characterized by the velocity vector of the flow, which is perpendicular to the velocity vector of deposition of solid granules of liquid gravel mix. The lack of vertical component of velocity vector makes settling solids on the bottom wall of the borehole. While settling granule gravel moves along the flow, the time of its deposition will affect for the path of its movement. Its shape, size, density, velocity diagrams of horizontal flow, viscosity and density of the liquid carrier also affects on this movement along the borehole. Swirling flow can be created not only through the use of specially designated device that swirl (active methods), but also by the ribs, forming surfaces, using screw guides,
winding-up etc. We distinguish types of swirling flows in channels that meet basic types of swirling. These are:

- damped swirling flows that occur in an unused channel that is located behind the swirling at the entrance;
- swirling flows with a constant level of swirling intensity, which is formed and maintained by swirling means along the entire length of the channel.

We have developed and patented [1] the design and technology of gravel filter installation using the flow tightening of working fluid during deposition of gravel filter pack-in.

Considering the hydrodynamic processes in channels with swirling of all types, we can say that the term "swirling flow" refers to two characteristics of the flow: the fluid motion in the channel is simultaneously vortex and circulating (progressive rotation), that is characterized by local swirling $\omega$ and large transverse circulation of flow due to the presence of tangential velocity components, roughly equal to the loss rate in the channel [2].

The difficulty of solving the problem of shape influence of swirling on hydrodynamics in cylindrical channels using Reynolds averaging in time is due to the lack of a universal model for description of turbulent tensor (Reynolds') stresses in channels with complex configurations if they have areas of flow separation, swirling motion with variable intensity of swirling and other complicating factors.

![Cross-section of the channel with swirliers (screw guide)](image)

Spatial averaging is one of the ways to simplify the formulation of the problem and identify the influence of geometrical factors on the hydrodynamics of complex turbulent flows. While the use of spatial averaging leads to an approximate solution of the problem based on the consideration of integral equations, this approach makes it possible to develop methods of calculations that allow to take into account the influence of swirlers with different geometry on hydrodynamics in the channels.

Using the averaging by volume, the dimensions of which are defined by the characteristic scale of spatial inhomogeneities currents that associated with features of the geometry of complex channels, helps to come to the consideration of averaged continuum as an effective homogenized medium. In particular, the procedure application of local averaging by volume for turbulent flows and flows in porous structures can lead to a nonzero value of the average velocity at the wall, i.e. to the slip condition on the boundary. Therefore, the spatial averaging procedure requires redefining the boundary conditions and taking into account the maintenance of
integrated balance of momentum, mass, and entering the appropriate description of effective coefficients of momentum transfer, which is related to the friction with distribution of velocity averaged flow.

Problem setting of mathematical modeling of hydrodynamics of swirling flows in channels with swirlers can be simplified as compared with the setting in the form of known differential equations, in case of averaging these equations by space considering the characteristics of the geometry of the channels [3].

Fig. 2. Calculation model of annular channel with a random placement of screw guides: R1, R2 – inner and outer radii of the annular channel; r1, r2 – radii that limit the placement area of screw guides; r = r* – LMV – the line of maximum velocity uz = uz max; r = r** – ZVL – zero-voltage lines \( \tau_{r \phi} = 0 \)

Considering the specificity of turbulent flows in flowing swirlers, including the fact that the main features of currents are in the volume of annular module \( r_1 \leq r \leq r_2 \) (Fig. 1), where the spiral swirlers for the carrying out of procedure of the averaging volume choose an elementary volume \( \Delta V \) in a form of annular sphere with infinitesimal thickness and width \( \Delta z \):

\[
\Delta V = 2\Delta r \Delta r \Delta z,
\]

where \( \Delta r, \Delta z \to 0 \) (see Fig. 1). Region of the swirlers in a radius \( r_1 \leq r \leq r_2, r_2 \leq R \) and their cross-sectional shape can be random.

**Numerical calculations of currents**

An important feature of turbulent swirling flow of fluid in annular channels is a complex nature of the influence of inertial forces not only on the formation of averaged velocity fields and pressure in the channel, but also on the characteristics of turbulent wall surface transfer. This is due to the fact that besides the spatial curvature of the current lines of swirling flow, it leads to the transverse gradient pressure, the surfaces of channel, which are limiting the area of flow, have the opposite sign of curvature in relation to the flow. The local inhomogeneities of inertia forces near surfaces lead, on the one hand, to the stabilization of the flow and reduction of the turbulent transport near the convex surface of the channel, and on the other hand, they lead to destabilization of the flow and enhancing of turbulent transport concave surface.

**Parameters of liquid and gravel mixture**

<table>
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<tr>
<th>Parameters</th>
<th>Fluid density ( P_\text{s} ), kg/m(^3)</th>
<th>Fluid Viscosity ( \nu_\text{s} ), mPa·s</th>
<th>Gravel density ( P_\text{g} ), kg/m(^3)</th>
<th>Concentration of gravel ( K_\text{g} ), kg/m(^3)</th>
<th>Grain size gravel ( d_{\text{min}}, d_{\text{max}}, d_{\text{mid}} ), mm</th>
<th>Mass flow rate ( G_\text{s} ), kg/s</th>
<th>Volumetric flow rate ( Q ), m(^3)/min</th>
<th>Mass flow gravel ( G_\text{g} ), kg/s</th>
<th>Concentration of gravel ( K_\text{g} ), kg/m(^3)</th>
<th>The value of static pressure at the outlet ( P_\text{f} ), mPa</th>
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</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>1250</td>
<td>2</td>
<td>2630</td>
<td>100</td>
<td>0.2/0.4/0.3</td>
<td>20.83</td>
<td>1</td>
<td>1.67</td>
<td>100</td>
<td>0.786</td>
</tr>
<tr>
<td>Option 2</td>
<td>1250</td>
<td>30</td>
<td>2630</td>
<td>100</td>
<td>0.2/0.4/0.3</td>
<td>20.83</td>
<td>1</td>
<td>1.67</td>
<td>100</td>
<td>0.786</td>
</tr>
</tbody>
</table>
Fig. 3. Isolines of velocity in the pipe \( a \) – at the viscosity of the fluid \( \eta = 2 \text{ mPa}\cdot\text{s}, \) \( b \) – at the viscosity of the liquid \( \eta = 30 \text{ mPa}\cdot\text{s} \)

Fig. 4. The dependence of the value of the rotating component of the flow velocity \( V_u \) from the path length \( L \) ( rhombus - at the viscosity of the liquid \( \eta = 2 \text{ mPa}\cdot\text{s}, \) circle - with the same viscosity of the fluid \( \eta = 30 \text{ mPa}\cdot\text{s} \) )

Fig. 5. Trajectory of the particles of gravel \( a \) – at the viscosity of the liquid \( \eta = 2 \text{ mPa}\cdot\text{s}, \) \( b \) – at the viscosity of the liquid \( \eta = 30 \text{ mPa}\cdot\text{s} \)
According to the calculating analysis being carried out, it is important to highlight the following. The result of a complex influence of uneven distribution of forces of inertia and pressure on the flow during the swirling flow in annular channels is divergence of lines of maximum velocity rate (LMV) and zero-voltage lines (ZVL), i.e. the position of the points in which derivative of velocity is becoming zero along the radius and friction voltage are different. These circumstances should be considered for the organization of the calculation process (Fig. 2).

According to this scheme, it is assumed that the region of swirler location $r_1 \leq r \leq r_2$ can be random, and, in the extreme case, take the full width of the channel or be absent at all, i.e. $R_1 \leq r_1 \leq R_2, R_1 \leq r_2 \leq R_2$. The numerical solution of equations is conducted in the areas between each of the surfaces of the channel and maximum velocity rate LMV line or zero-voltage lines ZVL. The field of swirler location is highlighted in Fig. 2 with large shading, it can be placed on one or both sides of LMV and ZVL. The components of the tensor impedance $k_{ij}$ and hence the resistance components $f_{\varphi i} f_z$ are nonzero only in the middle of the field with $r_1 \leq r \leq r_2$ [3].

The use of the results of simpler models makes it possible to include them in iterative procedures for more complex variational finite-difference methods.

The number of nodes in the grid (finite elements) is sufficiently large. Then we give the results of numerical calculations for the geometry described swirlers.

The aim of this calculation was the modeling based on introduced equations of possibilities for sustainable rotational-translational motion of liquid and gravel mix using set screw guides on the outer surface of the tube concentrically located inside a pipe with larger diameter.

Three-dimensional model was created using the software package SolidWorks. The calculation was performed using the software package Ansys.

Initial data for calculation

The parameters of gravel-liquid mixture, which are close to the actual parameters, were set to perform the numerical calculation. The following table describes the parameters of liquid and gravel mixture.

The calculation was carried out for three western screw guides. The length of pipe was installed in 5 m. The move of the guide screw is 0.5 m.
The calculated grid is unstructured, tetrahedral. Near the walls of the pipe and screw guides 10 layers of prismatic cells are mounted for improved scaling of the wall layer. The number of cells of calculated grid is approximately 3,350,000. According to the calculation results pressure losses are obtained in the pipe five-meter length $\Delta p = 1112$ Pa – for fluid viscosity, $\nu = 2$ mPa·s, $\Delta p = 1804$ Pa – for the same viscosity of the fluid $\nu = 30$ mPa·s.

Fig. 7. The dependence of the rotating component of the flow velocity ($V_u$) of path length ($L$) at the viscosity fluids $\nu = 2$ mPa·s (channel with a screw guides – rhombus, channel without screw guides – circle)

Figure. 8. Trajectory of the particles of gravel ($a$ – at the viscosity of the liquid $\nu = 2$ mPa·s, $b$ – at the viscosity of the liquid $\nu = 30$ mPa·s)

Fig. 3 shows the line of fluid current in motion in the annular channel in the presence of a screw guides. It can be seen that the flow passing over 25 % of the way, has a stable rotational-translational motion.

It is seen more clearly the presence of the annular velocity of the flow in quality and quantitatively, which is illustrated in Fig. 4 in a graph that represents the dependence of the flow value of annular velocity from the path length. It should be noted that the greater viscosity is, the slower increase of annular component is.

Fig. 5 shows the trajectory of the grains of gravel in the annular channel in the presence of a screw guides.

It may be noted that the greater the viscosity of the liquid is almost all granules are suspended, and with less viscosity the solids are left in the bottom wall of the outer tube (both with screw guides).

The calculation in the channel without screw guides

As a comparison, we can give the above described calculation of the initial data, which was performed for the annular channel without screw guides. Estimated grid is structured hexahedral.
Near the walls of the pipe and screw guides there are seals done to improve grid scaling of the wall layer. The number of grid cells is around 350 000.

According to the calculation results the value of pressure losses in the pipe of five-meter length is obtained $\Delta p = 531$ Pa – for the viscosity of the fluid $V_{ж} = 2$ mPa·s, and  $\Delta p = 766$ Pa – for the viscosity of the fluid $V_{ж} = 30$mPa·s

Fig. 6 shows the line of fluid path in motion in the annular channel in the presence of a screw guides. It is evident that the process is without annular component

Fig. 7 shows the comparison of dependency of the annular velocity component of the path length. We can say that the annular component in the channel without screw guide is practically zero.

Fig. 8 shows the trajectory of the grains of gravel in the annular channel without screw guides. It is evident that with less viscosity of fluid gravel granules begin almost immediately to settle to the bottom and then to roll along the bottom. With greater viscosity granules settling takes place away from the entrance to the channel, and it is clear that some of the solid phase moves without depositing until the end of the channel.

Using the known results of swirling flows it can be concluded that the proposed model is suitable for numerical calculations of flows in annular channels with swirlers. Spatial averaging, taking into account stationary, phenomenological assumptions lead to a set of basic models that can be used for decision support systems with structural optimization of swirlers that are used in the oil and gas industry, in particular for making gravel filters in horizontal wells.

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OIL AND GAS PRODUCTION

Impact of oil on the vibration behavior of the pumping unit gear

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To reduce power losses due to friction and to reduce the deterioration intensity of surfaces wear, and to prevent jamming, burrs, corrosion and better heat removal the interacting surfaces of parts shall have proper lubrication. Lack of lubricant, its nonconformance with the recommendations of manufacturers and pollution cause heavy wear, breach of geometrical dimensions and increase in clearance.

Heavy wear of working surfaces is one of the main reasons for decrease in efficiency of reduction units of stepping oil-well pumping unit (SOWPU) SOWPU. Therefore it is important to find proper lubricants for reduction units and define their lubricating properties. Over time, the quality of oil deteriorates, condensate is created, and therefore it is necessary to evaluate the effect of lubricants on reduction units’ performance.

The wrong choice of lubricant or its untimely replacement can lead to changes in center-to-center distance, shaft misalignment, worsening of working conditions of parts and acceleration of their breakdown. Therefore it is necessary to evaluate the impact of lubricants on the vibration characteristics of a reduction unit.

It is particularly important to analyze the factors of influence of the quality of lubricants on the wear process of working surfaces of the teeth and the methods and means of control of their technical condition during lubrication of SOWPU reduction units’ toothed gearing.

In mechanical engineering, crankcase lubrication system is widely used for gear lubrication. Surfaces of SOWPU reduction units’ toothed gearing are lubricated by immersion into a liquid lubricant bath. Oil is poured into the gear case so that the teeth row is completely immersed in it. During rotation oil is gathered by the teeth, is sprayed and penetrates into the inner walls of the casing and flows down to its bottom. A suspension of oil particles in the air is generated inside the casing, that cover the surfaces of parts located inside the casing.

Lubricants are used to reduce expenditure of energy for friction, reduce of the temperature of parts of movable coupling, removal of wear products, surface protection against corrosion and also contribute to the maintenance of the temperature regime of parts.

In double and triple-reduction units with common oil bath, oil with a viscosity with qualities between those essential for high-speed and low-speed steps is used. At higher speeds the centrifugal force throws oil from teeth, and gearing works with insufficient lubrication. In addition, there is a significant increase in power loss for oil mixing and its temperature also increases. A proper lubricant is chosen based on the experience in operation of machines. The principle of choice of a proper lubricant is as follows: the higher the tooth contact pressure, the greater the viscosity of the lubricant should be; the higher circular velocity of the wheel, the lower the viscosity should be. The required lubricant viscosity grade is determined depending on contact stress and angular velocity of the wheels.
During the operation, SOWPU reduction unit is constantly exposed to the external environment. Important physical and chemical property of oil is its ability to oxidize. In normal atmospheric conditions, mineral oils retain their properties for a long time. During operation and oil heating and its interaction with the air, its physical and chemical properties and performance are changed. This is manifested as formation of new products during oxidation: acids, resins, pyrobitumens, carbenes and carboids which in the most cases is the cause of complications during operation of heavily loaded gears and friction units, as well as of emergence of lacquer films on friction surfaces and sedimentation. Sometimes oils used for lubrication of toothed gearing become almost completely solid due to oxidation [1–7].

Viscosity of lubricants is the most significant indicator that determines whether they pass through the channels and small gaps of friction units.

The presence of moisture in lubricants significantly affects the quality of lubrication of parts of a reduction unit, which leads to wear intensification. Amount of moisture affects the nature of wear. If water content in oil is only 5% wear products are dark gray-brown and small, it contains a very small amount of metal particles. At humidity level of 50% (a monomolecular layer of water covers the surface) gray metallic powder is formed. Up to 50% humidity - wear particles mainly consist of oxides, at more than 50% - mostly of metal. The intensity of wear is significantly affected by film which is formed on the friction surface.

An inspection of equipment delivered for repair was conducted at Boryslavska service center, in particular, amount of oil in the crankcase and its quality were determined. Each piece of equipment was characterized by low oil level in the crankcase, besides oil it also contained a sufficient amount of water and oil of unknown origin (Fig. 1). The studies of the study are presented in Table. 1.

Table 1

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Crankcase volume, l</th>
<th>Factual volume of scavenged oil</th>
<th>Water content, l</th>
</tr>
</thead>
<tbody>
<tr>
<td>RU* Ts2NSh-750</td>
<td>135</td>
<td>85</td>
<td>20</td>
</tr>
<tr>
<td>RU Ts2 NSh -750</td>
<td>135</td>
<td>42</td>
<td>12</td>
</tr>
<tr>
<td>RU Ts2 NSh -315</td>
<td>37,8</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>RU Ts2 NSh -450</td>
<td>109</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>RU RN-650</td>
<td>63</td>
<td>22</td>
<td>4</td>
</tr>
</tbody>
</table>

*RU – reduction unit

The presence of water in lubricant almost always has a negative impact on work unit friction because it causes corrosion of metal surfaces. After stopping of a reduction unit and cooling of hot parts water condenses on the walls of crankcase and details. High level of humidity and penetration of water into the crankcase greatly enhances the intensity of corrosion. So, in this case, lubricants should be of high demulsifying properties, including the ability to provide rapid water sedimentation and prevent formation of stable water-oil emulsions.

It is possible to neutralize the effect of water on wear toothed gearing using soft metals as additives to the oil.

Corrosivity of oil depends on presence in it not only water, but also acid additives containing chemically active substances, that are corrosive towards metals. Low molecular weight acids react with metals even at normal temperatures, while high molecular weight acids react with oil in the presence of water and oxygen through hydroxide. The property oil to protect parts from corrosion in the presence of water and oxygen can be improved through the use of
additives Technical maintenance of reduction unit is basically a systematic lubrication of units and a timely replacement of scavenged oil. The maintenance also includes elimination of leaks in the lubrication system.

Different factors influence on the lifetime of SOWPU reduction units. It is necessary to look for new approaches to improve their lifetime. Increase in the load or contact pressure results in increased heat generation in the contact patch and therefore increases the likelihood of a gear pair wear. Load increase without additional heat removal leads to an increase in surface temperature, reducing oil viscosity at inlet and increasing coefficient of friction, so that different kinds of wear occur.

Vibration resulting from manufacturing and assembly errors has a significant impact on carrying capacity of hydrodynamic oil film.

Viscosity is the main indicator of the property of the oil to create an oil film with high load capacity, which prevents from and reduces surface wear. Oil viscosity depends on various factors, primarily on temperature, i.e. viscosity decreases with increasing temperature. It is established that in the same operating conditions more viscous oils form a thicker film which simultaneously increases its carrying capacity and thus reduces wear compared to less viscous oils. Besides that, the ability to prevent or reduce oil wear depends on the type of film that is formed on friction surfaces through the use of surface-active or inactive oil.

Studies suggest that reducing the roughness of working surfaces of wheel teeth can significantly reduce the maximum instantaneous temperature in the contact zone of the teeth. Perhaps there is some optimal surface roughness which provides the largest carrying capacity of a transmission. In addition, of importance are oil film thickness and total height of microroughnesses of conjugate surfaces of a toothed gearing.

To important physical and chemical properties of oil belongs its ability to oxidize. In normal atmospheric conditions, mineral oils retain their properties for a long time. But it changes its physical, chemical and performance properties during operation by heating, and interaction of oil with air in the presence of crystal-active components at high temperature. New products are formed during oxidation: acid, asphaltenic gums, carbenes and carboids that mostly cause complications during operation of heavily loaded gears and friction units, as well as of emergence of lacquer films on friction surfaces, and sedimentation.

Oil properties and its viscosity significantly affect the maximum instantaneous temperature at the surface of toothed gearings. Since the temperature spikes on the tooth surface are high at initial and final point of contact when sliding velocity is at its greatest value, edge shocks that lead to oil film dissection are possible.

The way and amount of oil feed also play a significant role in occurrence of different kinds of wear.

As for gear SOWPU reduction units are characterized by operation at the time of launch, it is particularly important in the event of a load. A thin oil film must be maintained on friction surfaces, oil excess must be removed from the friction zone prior to coming into direct contact, otherwise expenditure of energy for squeezing and spraying of oil on the friction surfaces can be increased. Ideal lubrication takes place when oil stream is fed into the exit area of teeth mesh. This results in rapid removal of heat with oil, it is discharged into the crankcase, and by the time of teeth mesh an effective thin oil film remains on their surfaces.

Determination of vibration levels of a reduction unit, depending on the oil quality in a reduction unit crankcase and at the time of launch under load, was conducted at the experimental test bench installation, which is a scalable model of a SOWPU reduction unit type Ts2NHHh-750B. The model is equipped with a 2.2 kW electric motor with a nominal speed 1420 rpm, two cone-belt drives with a total reduction ratio of 5.53, a reduction unit with a total reduction ratio
Load on a balancer head is fed by a 600 mm long spring with a diameter of 45 mm. Vibration signal was measured on the casing of a reducer closest to output shaft bearing by means of information-measuring system, comprising a piezoelectric transducer, an amplifier, an independent power supply and a laptop. The signals were processed in the Mathcad environment.

We used scavenge and pure I-40 oil for the investigation. We obtained scavenged oil from a SOWPU reduction unit that had been operating for 5,000 hours. Fig. 2 and 3 show frequency spectra depending on oil quality in the crankcase gear. Comparison of Fig. 2 and 3 indicates that oil quality significantly influences on spectra of a vibration signal. In the low-frequency part of the spectrum, this effect manifests itself mainly in the first few harmonics of frequency of teeth mesh. In particular, the most significant is the increase in the amplitude of spectral components of vibration signal at the second double frequency of teeth mesh (Table 2).

Table 2 Vibration amplitude at teeth mesh frequency harmonics for a high speed shaft in case of use of I-40 oil of different quality

<table>
<thead>
<tr>
<th>Teeth mesh frequency and its harmonics</th>
<th>Amplitude, relative units</th>
<th>Amplitude growth, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I-40 oil (clean)</td>
<td>I-40 oil (scavenge)</td>
</tr>
<tr>
<td>Fz1</td>
<td>5</td>
<td>4.7</td>
</tr>
<tr>
<td>Fz1*</td>
<td>40</td>
<td>69</td>
</tr>
<tr>
<td>Fz1*</td>
<td>50</td>
<td>71</td>
</tr>
<tr>
<td>Fz1*</td>
<td>107</td>
<td>164</td>
</tr>
</tbody>
</table>

In addition, growth of virtually all vibration frequencies from 500 to 2000 Hz (Table 3) is also essential. Higher frequencies do not take into account low sensor sensitivity at the high-frequency range (vibration level amounts to almost zero at obtained frequencies over 3000 Hz, and in 2000 ... 3000 Hz range spectra difference is negligible with an allowance for errors).

Table 3 Vibration amplitudes at middle and high frequency ranges in case of use of I-40 oil of different quality

<table>
<thead>
<tr>
<th>Frequency range, Hz</th>
<th>Average vibration level at the frequency range, relative units.</th>
<th>Vibration level increase, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I-40 oil (clean)</td>
<td>I-40 oil (scavenge)</td>
</tr>
<tr>
<td>350...450</td>
<td>20.9</td>
<td>33.8</td>
</tr>
<tr>
<td>500...700</td>
<td>39.1</td>
<td>72.9</td>
</tr>
<tr>
<td>700...1000</td>
<td>42.6</td>
<td>115.2</td>
</tr>
<tr>
<td>1000...1200</td>
<td>20.6</td>
<td>92.7</td>
</tr>
<tr>
<td>1200...1350</td>
<td>36</td>
<td>254.8</td>
</tr>
<tr>
<td>1350...1450</td>
<td>31.1</td>
<td>154.5</td>
</tr>
<tr>
<td>1450...1700</td>
<td>75.8</td>
<td>167.8</td>
</tr>
<tr>
<td>1700...1780</td>
<td>88.7</td>
<td>100.1</td>
</tr>
</tbody>
</table>
In the Tables 2 and 3 amplitude is measured in relative units – counts of an AD converter used in the research.

A significant increase in vibration level is observed for the range of 1000 ... 1700 Hz, that corresponds to vibrations caused by friction between the elements of reduction gearing construction. It can be explained by the fact that scavenge oils usually contain large amounts solid impurities, that are formed as a result of destruction of gear units material during the process of wear. The presence of impurities leads to increase in friction and therefore increase in vibration level.

Therefore, the deterioration of oil in the gearbox during wear leads to increased vibration. This in turn may accelerate the process of deterioration and reduce no-failure operation of a reduction unit. Therefore, timely replacement of oil is an important factor in improving the reliability of SHHNU reduction units.

During an oil replacement it is necessary to consider that characteristics of oil poured into the crankcase gear are the same or slightly better than in the passport of the reduction unit.
Modern industrial machinery must be designed to ensure small material and energy costs during their manufacture, as well as great life length and reliability with minimal operating costs and maintenance. Full implementation of the technical and economic potential of the equipment is possible only in the case of lubrication of friction couples with the use of quality lubricants that fully meet operating conditions of their use.

Modern lubricants capable of withstanding high mechanical and thermal loads, reducing energy consumption and provision of protection against wear, corrosion and deposit formation that infringe the normal operation of the equipment. High performance of lubricants is achieved by of special alloyage with the use of additives with different functionality.

A wide range of lubricants is created to meet the consumers’ requirements for this kind of products, including engineering companies, as well as with due compliance with the requirements of applicable regulations, in order to meet specific tasks of lubrication of machines.

Modern requirements for lubricants are based on well-known and practically applicable classifications and specifications, which specify the most important characteristics of lubricants in the form of test results obtained with the help of a famous (in most cases standardized) method. This makes it possible for all interested parties (manufacturers of lubricants, engineering companies, and consumers of their products) to share complete information about the properties of lubricants and their appropriate use.

Considering the aforementioned we can draw up the following conclusions.

With the development of technology, increase of lifetime and reliability of machines are becoming more and more important, therefore study of causes of breaking of parts during operation and development of methods for increasing of durability of machines is urgent.

Increase in durability of machine parts leads to costs reduction for spare parts and materials for their production, reduce of staff and labor intensity during operation, maintenance servicing and repairs.

Difficult operating conditions of modern machinery have rapidly increased requirements for lubricants.

Deterioration of oil quality during wear of a reduction unit leads to increased vibration levels. This in turn may accelerate the process of wear and reduce reduction unit lifetime. Therefore, timely oil replacement is an important factor in improving of the reliability of SOWPU reduction units.

One of the most urgent tasks of modern engineering is rational use of oil, which in many cases determines performance and durability of machines.
During lubricating and filling works it is important to strictly adhere to deadlines and use oil sorts recommended by the manufacturer.

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OIL AND GAS PRODUCTION

Interaction of silicate rocks with clay-cut acid muds in thermobaric conditions of bed. P.I. Influence of pressure on the solubility of rock.

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Yu.D. Kachmar candidate of technical science
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УДК 622.276

The paper examines dissolution properties of each component of oxides (silicon, aluminum, iron, calcium and magnesium) of Alta-Mud by acid-cut clay mud with increasing pressure. Dissolution of clay mineral sample by acids depending on pressure is an amount of dissolution of each metal oxide. In this case, dissolution of silicon and aluminum oxides with raising pressure increases and concerning other oxides it decreases.

To receive the maximum technologic effect (CAM) on the base of hydrochloric and hydrofluoric acids during the acting to the terrigene rocks it is necessary to consider the mechanism of interaction of acid mixture with the rock components. During the projecting of technology of clay and acid acting it is necessary to consider the degree of rock solubility of CAM which depends on temperature and pressure and possibility of creation of water-insoluble products of heterogeneous response, which presence influences upon the increasing of penetrating of producing formation.

The influence of pressure during interaction of acid solution with silicate rock is not studied enough nowadays. If the response of acid neutralization passes without the emission of gaseous carbon dioxide (CO2) and silicon fluoride (SiF4), the pressure is almost not affect the speed of the response. If the response takes place with the emission of gaseous products, the increase of pressure causes the slowdown of the response. For example, the half-time (half decrease of the concentration of acid) of hydrochloric acid in the interaction with calcium carbonate (marble) increases 8-9 times when pressure is 5-9 MPa and temperatures lower than 37 degrees, compared with atmospheric conditions [1].

The proposed research is the continuation of works as for the studying of CAM (10 % HCl+1 % HF) with silicate rocks of Prykarpattia (dispersed clay and carbon sandstones and gorodyshchensky clay powder) under the atmosphere pressure) and depending the temperature in the range 40–80 °C. The indicated researches were conducted at the atmosphere pressure and temperature more than the critical one at which the gasous products of response are released. The indicated conditions do not correspond the conditions of interaction of CAM with the formation during the clay and acid action (CAA) when the formation pressure is significantly higher than the atmosphere one [2]. Therefore to understand the process of interaction of silicate rocks with CAM and study the peculiarities of heterogeneous response it is necessary to conduct thye experiments with mixture of phases at the simultaneous action of tension and temperature id est in thermobaric conditions close to the formation ones.

The researches were made by means of simultaneous influence of temperature and tension on the dissolution of samples of silicate rocks and the order of release of metal oxides from ther was defined. The interaction of different acid solutions (10 % HC solution 1, 3 % HF solution, CAM at the base of mixture 10 % HCl and 1 % HF) with gorodyshchenskyi bentonite clay powder was studied in autoclave at the temperatures 40 i 80°C and pressure 5, 10 and 15 MPa [3]. Bentonite clay powder from gorodyshchenskyi mine was used for dissolution which contains...
0,667 g SiO$_2$, 0,124 g Al$_2$O$_3$, 0,056 g Fe$_2$O$_3$, 0,014 g CaO, 0,012 g MgO in one gram of batch.

Fig. 1. Influence of pressure to the consumption of acid during the dissolving of gorodyshchensky clay powder by the hydrochloride or hydrofluoride acid: 1 – 10 % HCl; 2 – 3 % HF

Fig. 2. Dependence of solubility of gorodyshchenckyi clay powder of the pressure at the temperature 40 °C – curves 2, 4, at 80 °C – curves 1, 3;
The using of gorodyshchensky clay powder gives an opportunity the results of researches received preliminary for comparison. [2]. The surface area of clay powder defined by the method of sedimentation analysis is 0,08 m²/g. So, the ratio of acid volume to the external rock surface is in the range from 310·10⁻⁴ cm³/cm², which corresponds to the ratio of acid solution volume to the cylindrical channel surface with a radius 40–620 mm. The described methods of researches conduction ensured the creation of conditions of passing of dissolution response similar to the formation ones. The analysis of chemical content of clay powder and undissolved rest was made according the standard methods of analysis of silicate rocks. [4, 5]. Determination of general acidity of initial filtrate of acid solution are made by the methods [6], which provide the defining of free acid if the salts of aluminium and iron are present.

The mining zone of formation from the well bore to the front of movement of active acid in the pore environment can be devided into two large zones. The first one is the zone of excess of acid over the rock which is characterized by the high residual acidity of the solution (from 99% at the input to the perforation holes to 10% at certain distance from the well bore). The second is the zone of excess of rock over the acid which is characterized either with the slight acidity of Solution (up to 10%) or the full neutralization of acid solution and possibility of sedimentation of slightly solluble and nonsolluble products of the response. The indicated zone is located closer to the front of movement of active acid. Therefore the experimental researches of solubility of rock must be carried out as for the conditions of excess of acid over the rock and the excess of rock over the acid. The ratio of volume of acid to the mass of clay powder was chosen so to model the indicated opposite conditions: thye excess of acid was created at the correlation 2 g of rock for 50 cm³ of acid solution and the excess of rock - 10 cm³ CAM for 5,5 g of rock. Curing time of acid solutions for thof solubility of rock was 15 min. It is connected with that. Earlier it was found out that the neutralization of clay and acid solution in the pore environment occurred during first minutes of its pumping which ensures the dissolution of 85% of soluble components of silicate mineral during 15 min [7]. Consequently the indicator of curing (15 min) is rather informative and defining for understanding of mechanism of interaction of acid solution with rock components in the initial period of pumping of the acid to the formation.

Solubility of bentonite powder from gorodyshchenskyi mine under different pressure was studied both in separate solutions of hydrochloride and hydrofluoride acids and in the clay and acid mixture.
The solubility of clay powder in 10% solution HCl or 3% solution HF was defined at the temperature 80 °C and during the curing during 30 min with the correlation of the batch to the volume of the acid as 1g to 50 cm3 (condition of excess of acid over the rock). Received results are given on Fig.1. They testify that the pressure increasing up to 10MPa causes the increasing of consumption of hydrofluoride acid approximately 20% and slowing down of degree of neutralization of hydrochloride acid on 30%. As a result the solubility of bentonite is decreased from 10,7 to 7,7% during the using of the hydrochloride acid. As for hydrofluoride acid the solubility of bentonite with increased pressure up to 10 MPa is increased from 56 to 75%. At this the biggest influence of pressure is observed in the interval from 0,1 to 1 MPa and its further increasing practically does not influence on the change of consumption of one or another acid.

The studying of process of dissolution of gorodyshehenskyi bentonite clay powder in the mixture of hydrochloride and hydrofluoride acids in different conditions (temperature 40 and 80 °C, excess of acid or rock) shows that increasing of pressure from 0,1 to 15 MPa in the case of short-time curing (0,25 h) practically does not influence the sample solubility – it is stabilized at the certain level. (Fig.2). The received results testify that researches of soluble ability of bentonite clays in the different acid solutions can be conducted at atmosphere pressure to simplify the methods of researches, because the maximum deviation of true meaning at the given pressure on this material does not exceed 10 % (wich is within the admissible errors of the experience). The indicated exception does not concern the other samples of silicate rocks for which the significant influence of pressure upon the solubility capacity is possible (it is necessary to conduct the corresponding researches for each specific mineral).

The quantity of received results is not sufficient to define the influence of pressure to the dissolving capacity of acid solutions for silicate materials. Such factors as temperature increasing, curing time and correlation of acid volume to the rock surface ensure the increasing to some extent of the solubility of clay powder in the mixture of hydrochloric and hydrofluoric acids.
acids. The most important factors as for the increasing of speed of solubility is the correlation of the volume of acid to the rock surface and increasing of temperature. It is set that the mass of dissolved rock for one gram of its initial mass of sample for 15 minutes of interaction at the excess of acid (curves 1, 2, fig. 2), in comparison with the excess of rock (curves 3, fig. 2), are increased three (from 0,1-0,12 g/g to 0,34-0,36 g/g). Correspondingly the temperature increasing from 40 to 80°C to less extent but also ensures the increasing of solubility of clay powder in the acid mixture.

The dissolution of base oxides which are the base of bentonite clay powder is the critical for understanding of the mechanism of influence of pressure on the speed of dissolution of silicate rocks. (fig. 3-7). The previous researches found out that at the excess of rock for 15 minutes of curing at the temperature 80 °C and atmosphere pressure the biggest indicators of dissolution belong to calcium (64 % of the clay powder content in the sample) and magnium oxide (60%) and iron oxide (62%). The aluminium oxide is sustained only on 30% and silicon oxide is not dissolved at all. The pressure increasing from 0,1 to 15 MPa causes the partial (5-10%) decreasing of sustaining of calcium, magnium and iron oxides and increasing 2-3% of the sustaining of silicon oxide at the excess of rock and 5-15% at the excess of acid (fig.3) and aluminium oxide on 3-15% of their content in the sandstone (fig.4). Such an increasing of the quantity of dissolved oxides Al2O3 and SiO2 is connected with the improving of conditions of penetrating of both acids (but especially hydrofluoric which is shown on fig. 1) to the centre of silicon tetraedres where mainly ions of silicon and aluminium are located. The decreasing of temperature of interaction 80 to 40 °C causes the decreasing of quantity of all suspended oxides on 5-10%.

In the case of excess of rock the process of dissolution of aluminium oxide with increasing of pressure tends to increase (fig.4) which is intensified with increasing of temperature. At the same conditions during dissolution of iron oxide with increasing of pressure on the contrary we can observe the tendancy for decreasing (fig.5) and the temperature increasing ensures the increasing of oxide dissolution.
In the case of excess of the rock the dissolution of calcium oxide (fig.6) and magnesium oxide (fig.7) with the increasing of pressure tends to decrease and the increasing of temperature ensures the increasing of oxides solubility.

The acid excess (conditions created following the front of movement of first portions of acid and specific for the majority of acid and clay mud) promotes more complete suspension of researched oxides especially silicon oxide. For silicon oxide such an increasing is 7-10 times and for the other oxides – only 15-2 times in comparison with indicators specific for the condition of excess of rock over the acid. At this it is also necessary to consider that in case if excess of acid for short time (15 min) of interaction almost all oxides of two and three valent metals are dissolved and partially silicon oxides which are the components of silicate mineral (silicon oxides in the form of quartz do not undergo the acid action). The power increase from 0,1 to 15 MPa causes partial (5-15%) decrease of sustaining of calcium, magnesium and aluminium oxides, slight change of quantity of iron oxide and the increase of sustaining of silicon oxide for 5-15% of their content in the rock. Id est the pressure increase in the case of excess of acid works as the factor of decrease of solubility of most oxides of silicate minerals. In case of excess of the acid the process of dissolution of aluminium oxide with increase of pressure tends to increase (fig. 4). Excess of acid during the dissolution of iron oxide with the pressure increase tends to decrease (fig.5) except the case of short-time curing of the solution with the rock under the temperature 40 °C. In the case of excess of acid the dissolution of calcium oxide (fig.6) and magnesium oxide (fig.7) with increase of pressure tends to decrease. As the main part during the dissolution of betonite is the oxides of aluminium and iron, and less – oxides of calcium and magnesium then
when increasing the pressure we can observe either the decrease of sample solubility of the clay powder or the stabilization of solubility at certain level (i.e., increase of solubility of silicon oxide does not compensate the decrease of solubility of basic oxides of clay powder).

The carried out researches of solubility of gorodyshchensky bentonite clay powder in the mixture of 10% hydrochloride and 1% of hydrofluoride acids at the increased pressures testify that increase of pressure of interaction from the atmosphere to 15 MPa results either decrease of solubility of clay powder sample, or to the stabilization of solubility at certain level in the case of using of 10% HCl and 1% HF. In the case of independent using of 3% solution HF with the increase of pressure on the contrary we can observe increase of solubility of bentonite clay powder. Such a difficult character of dependence of solubility of silicate rocks and minerals by acids of the pressure of interaction can be explained only the dependence of quantitative composition of carbonate and silicate components in the terrigene rock. At this when increasing the pressure of interaction the silicon oxides and aluminium oxides ensure increase of solubility of samples of terrigene rocks and the oxides of iron, calcium and magnesium – on the contrary, decrease of samples solubility.

Fig. 6. Dependence of solubility of calcium oxide from gorodyshchensky clay powder of the pressure and temperature: at 40 °C curves – 2, 4, at 80 °C – curves 1, 3; at curving time 15 min and excess of: 1, 2 – acid; 3, 4 – rock
Thus, during the interaction of any sample of silicate mineral with acid solution of the diversie composition, its solubility is the sum of the solubility of all basic oxides of metals of this sample. Consequently, dependence of the general indicator of solubility of various factors will depend on their influence on the solubility of each particular oxide and its part in the total amount of dissolved material. This interaction mechanism can be explained by the previously obtained results concerning the influence of pressure on the solubility of different rock samples. So, if the hydrochloric acid is used independently, the carbonate components are dissolved primarily and partially oxides of iron and alumnum. In connection with the dissolution of three of four oxides with slowed character with increasing of pressure for a general increase of pressure of bentonite clay powder one can observe the decrease of level of neutralization of hydrochloric acid by 30%.

With the increase of part of carbonate components in the rock (for example, in the carbonate sandstone up to 15%) the rate of dissolution slows in 1.5-2 times [3]. In the case of independent use of hydrofluoric acid the dissolution of oxides of silicon iron and alumnum prevails. In connection with the dissolution of two of three basic oxides with accelerated character with increasing pressure for the general solubility of bentonite clay powder the increase in the degree of neutralization of HF by 20% is observed.

If we use CAM, we can observe the dissolution of all five oxides of bentonite clay powder, so the total solubility sample is defined as their sum. As the total solubility of bentonite decreases with increasing pressure, then this suggests that the solubility of iron calcium and magnesium oxides prevails the solubility of silicon and aluminium oxides. Consequently the general solubility of bentonite in such conditions is insignificant and amounts to a maximum of 10%. Under certain conditions (short interaction time, the excess of the rock over acid) the growth of solubility of silicon and aluminium oxides is comparable with the decrease of solubility of iron oxides, calcium and magnesium, therefore, the general sample solubility with increasing pressure is stabilized at a certain level. The received results of experimental
The solubility of bentonite clay powder under the increased pressures depends significantly of the composition of acid solution. Thus, in the case of use of hydrochloric acid as for the carbonate rocks the solubility of clay powder slows down with increase of pressure. If the hydrofluoric acid is used the solubility of clay powder on the contrary increases with pressure increase. In the case of applying of acid clay mud at the base of 10 % HCl and 1 % HF the solubility of clay powder with pressure increase for the short time of interaction either does not change or slows down. Consequently the experimental researches concerning the study of solubility of bentonites in acid solutions of various content can be carried out according the simplified methods – at the atmosphere pressure because it simplifies the carrying out of the researches themselves and gives an opportunity to receive meanings specific for the formation conditions.

The order of dissolution of oxides at the absolute meaning from the composition of bentonite clay powder in conditions of excess of acid for 15 min of curing at pressures from 0,1 to 15 MPa actually corresponds the initial distribution in the rock sample (almost all oxides R2O3 and RO are soluble and partially RO2. In conditions of rock excess the selective dissolution of oxides occurs (R2O3>RO>RO2).

It is found out that the solubility of any silicate sample by the acid solution of various composition at increased pressure is the sum of solubility of all its basic metal oxides. At this silicon and aluminium oxides with the increase of pressure of interaction ensure the increase of solubility of samples of terrigene rocks and iron, calcium and magnium oxides with increase of pressure – decrease of samples solubility. As the mineralogic composition of silicate minerals is various then the dependence of their solubility in clay and acid mudes at thermobaric conditions may differ from the received dependence for aluminium silicate (bentonite clay powder). Therefore the indicated researches must be continued at least for the main classes of silicate minerals.

References


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TRANSPORTATION AND STORAGE OF OIL AND GAS

Corrosion and mechanical testings of tube steel for forecasting of life of oil pipelines

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УДК 621.438:622

The paper shows the results of experimental studies of corrosion and mechanical and corrosion characteristics of pipe steels of the pipelines in corrosive medium models, graphic dependences are constructed for the analysis of corrosion and mechanical processes.

During the accidents at oil pipelines a three-phase system goes to the environment the which gasous phase contaminates the air basin and the liquid and solid phase – ground forming the areas of pollution therefore the studying of characteristics of corrosion and mechanical processes of the tube body which have been operating 15-20 and more years is an actual scientific task.

The seamless tubes with the wall thickness 15 mm used for the construction of pipelines are chosen to be the object of research.

To investigate the corrosion processes under the tension we used the developed computerized system KH-1 created at the base of the system MB-1K [1].

The testings of samples from pipeline material in air and in liquid working environments were conducted in the mode of static load by clean fold with automatic registration of the sample flexure and change of electrode potential with the help of the computer using 24-bit analogous and digital conversion of meanings number.

The flat samples from the material of different areas of linear pipeline part were used. Such a technology provides the high accuracy and given roughness of working surfaces during the using of mechanical treatment with programmed change of feeding.

In the process of static load and creep a parameter of which it is possible to define the arrow of flexure of sample $\delta$ is constantly registered. Parameter $\delta$, working part length $lp$ minimum radius of sample curvature $P_{\text{min}}$ with the correlation

$$P_{\text{min}} = \frac{l^2}{8b} + \frac{\delta}{2}$$

The relative deformation of last fiber was defined at the formulation

$$\varepsilon = \frac{1}{2l'_{\text{min}} + 1}$$

where $b$ – sample thickness.

The complex analysis of internal and external factors which characterize the speed of corrosion of pipes material in operation environment is necessary to forecast the corrosion behavior of pipelines.

The main indicator of speed of corrosion destroying (both partial and even corrosion) is the depth of penetrating. In both cases the depth of corrosion destroying regardless of kind of metal or alloy is measured in millimeters per a year.

The speed of corrosion is defined under the formulation
where $m_0$ – initial sample mass, kg; $m_1$ – sample mass with the products of corrosion, kg; $S$ – sample area, m$^2$; $t$ – time of experiment, years; $n$ – coefficient which depends on the content of products of corrosion. The preliminary preparing of experimental samples includes their mechanical treatment with the help of small-disperse abrasive, degreasing by organic solvent (acetone, toluol or benzol) and weighting on the analytical balance. The samples are placed in the glasses with the solutions which model the aggressive environment. After finishing the experiment the samples are removed from the solutions, the dimensions of surface are to be measured quickly which was dipped into the aggressive environment, the insoluble corrosion products are to be taken away from their surface by the wet sponge.

After the washing by distillate and thorough drying by the filtering paper the samples are to be weighed again at the analytical balance.

![Fig. 1. Nominal diagram of deformation of steel samples of pipeline in air](image)

During the measuring of potentials chlorsilver electrode of comparison was used.

In order to model stress and corrosion processes with the highest accuracy we made the analysis of formation waters and subbottom water at different stages of transportation of crude oil. At this base 3 model environments were chosen which correspond the formation water of the well, and subbottom – at the stage of transportation and selection at the pumping station [2].

**Table Composition of model environments (ME)**

<table>
<thead>
<tr>
<th>Model environment</th>
<th>Sample origin</th>
<th>pH</th>
<th>SO$_4^{2-}$</th>
<th>NO$_3^-$</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Selection for ME</td>
<td>6.2</td>
<td>2.8</td>
<td>4.8</td>
<td>4.0</td>
</tr>
<tr>
<td>2</td>
<td>Formation water</td>
<td>6.0</td>
<td>3.6</td>
<td>7.6</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>Subbottom water</td>
<td>6.1</td>
<td>7.5</td>
<td>5.3</td>
<td>5.1</td>
</tr>
</tbody>
</table>
The long-lasting action of loads and influences in ground massive to the pipeline metal causes various structural changes including deformation and relaxation of tensions. Therefore the studying of mechanisms of change of physical and mechanical properties of the material of pipeline in the process of long-lasting operation will give an opportunity to forecast more precisely the remaining life of work of the available pipelines. In current conditions when the essential part of pipelines have being operated 15-20 years and close to the exhaustion of its work life according to the preliminary data, the studying of their corrosion and mechanical behavior is the actual scientific task.

To build the nominal diagrams of deformation the apparent staged load (unload) of sample was used (fig.1) by clean fold when with the decrease of supporting of sample, the load which passes to is not decreased. With the increase or decrease of load for one level the nominal tensions were changed on the value \( \Delta \sigma = 20 \text{ MPa} \) for time \( t_{n-p} = 1 \text{ c} \). Curing time at each level was \( t_{b} = 19 \text{ c} \), and total time \( \Delta t = t_{n-p} + t_{b} = 20 \text{ c} \). Such a mode of load gives an opportunity to consider the backlog of deformation of the tension in time and study profoundly the processes of deformation strengthening and creep.

Experimental researches of creep phenomenon which results have being used recently more and more often in the engineering calculations and for optimization of pipelines constructions are conducted mainly during the stretching.
The creep is often considered as slow metal flow. As it is known the opinion of flow surface is in the base of the theory of plastic flow. In the process of static fold the regular moving of the surface of flowing occurs, id est its evolution.

The specific curves of creep in the coordinates of growth of creep $\Delta \varepsilon$–time $t$ is depicted on fig.2-4. The duration of tests in air was defined by the character and kinetics of the processing of each specific case which gave an opportunity to conduct the series of experiments for relatively short time and calculate the parameters of area of low-temperature creep.

![Fig 3. Creep of pipeline material at nominal tensions 250 MPa](image)

General growth of deformation $\Delta \varepsilon$ for time $t$ for this range of tensions can be defined at the formulation $\Delta \varepsilon = \Delta \varepsilon_{\Pi P} + \Delta \varepsilon_{\Pi L} + \Delta \varepsilon_{\Pi}$,

where $\Delta \varepsilon_{\Pi P}$ and $\Delta \varepsilon_{\Pi L}$ – correspondingly the growths of elastic and plastic deformation during the reaching of given level of tensions $\Delta \varepsilon_{\Pi}$ – creep growth.

It was set that the creep of the main metal in corrosive and active environment as in air has a staged character. The influence of environment is felt on stages of both stable and unstable creep. As the researches showed the pipeline steel shows the biggest tendency to low-temperature corrosion creep in MC2 and the smallest – in MC3.

The duration of the first stage depends more of the value of nominal tensions and less – of the chemical composition of environment. The studying of dependencies of the growth of corrosion creep of the value of nominal tensions and chemical composition of environment give an opportunity to make conclusion that its maximum synergetic influence is observed in MC2, and the minimum – in MC1.

For the best studying of chemism of the process of internal stress-corrosion of pipeline steel and defining of the most dangerous operation environment from chemical point of view the kinetics of electrode potential was researched. It is known that lower metal potential and quicker the process of dis-elevation, the probability of corrosion processes is higher and consequently the unsafety of arising of corrosion damages.

As it is seen from the graphics the synergetic action of corrosion active environment and applied mechanical tensions takes place here also.

Now we'll study the influence of mechanical factor upon the process of diselevation. We’ll compare the kinetics of electrode potential at $\sigma = 1.6 \sigma_{0.2}, 1.35 \sigma_{0.2}$ and $1.05 \sigma_{0.2}$. The results of researches testify that with decrease of level of nominal tensions the speed of process of
diselevation in MC2 is practically unchanged, and in MC3 and especially in MC1 it is decreased significantly.

Thus MC2 is the most dangerous environment from chemical point of view, because the process of diselevation in it is controlled by the corrosive factor. It means that at minimum level of mechanical tensions the corrosion will occur rather intensely. In MC1 we observe the mixed control with the accent on mechanical factor. From chemical point of view it is frankly speaking is the most safety from our environments. In MC3 the situation is practically analogous but the very diselevation is less intensive.
As for the corrosion activeness it has the intermediate place.

The dependence of stabilizing potential of pipeline steel of its tension and deformed state is illustrated on fig.5.

As we can see it is rather notable especially in MC1 and MC2.

As we forecasted considering the kinetics of the potential the biggest speed of corrosion is observed in MC2, the smallest – in MC1. The low speed of corrosion in the latter case confirms our suppost that the fast decrease of electrode potential in MC1 is mainly connected with the processes of plastic flowing in pipeline steel which is accompanied inevitably by the creation of uenile surfaces and submicrotracks, the newly created surface of which has much more lower
potential as well as by the biggest relative content of chloride ions which prevent its fast passivation.

As for the decrease of the thickness of wall of pipeline we can see here that even at minimum level of tensions it can reach from 0.125 to 1.25 mm/year depending the chemical content of the environment and level of nominal tensions (fig.6).

It is set that with increase of value of nominal tensions of 1.05 ± 0.2 to 1.6 ± 0.2 the increase of general speed of corrosion in model environments can reach 25%.

Thus, during the calculation of remaining life of available pipelines and projecting of new ones we must not in any way neglect the mechanical factor. It is also necessary to consider the permanent intense movement of corrosive environment at which:

The constant washing-off of unsoluble products of corrosion i.e. the pasivation of surface becomes worse;

the tendancy to localization of corrosion processes occurs because the place damaged initially can not be pasived and therefore constantly has the less potential of the neighbouring nondamaged areas;

a galvanic element is created in which the damaged area becomes anode and the nondamaged one – cathode;

the speed of local corrosion can 2-8 times exceed the speed of general one.

Considering that under unfavourable conditions which we can not neglect the mechanical factor and factor of movement of the environment will reinforce mutually the corrosion processes it is not difficult to define that the speed of local corrosion and consequently the value of decrease of wall thickness can increase 2.5-10 times.

References

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Post-graduate of Ivano-Frankivsk National Technical University of Oil. Main sphere of scientific researches: studying of processes which occur with tube metals in pipelines during their longlasting operation; development and introduction of methods of repair of trunk pipelines without stopping of transmitting of the product to the consumer.
The paper proposes two ways to improve the reliability of rotating machinery of oil and gas industry through the use of rolling bearings that allow evenly distribute the pressure of lubricating fluid to the surface of the shaft.

In the oil and gas industry the machines and equipment are often used, which construction structure includes the knots of bearing type. The failures of bearing knots are often caused by an uneven distribution of load along the contact of a rotating body with the bearing unit. This in its turn leads to overheating, jamming and loss of productivity of machinery or equipment. In this regard, the durability and compactness of bearings, which are used in oil and gas industries, must meet rather strict requirements. This problem can be solved by creation of new progressive methods of working of the bearing units.

In the oil and gas industry the classic slide bearings are mainly used, which are widely used in gas-pumping equipment, pumps and drilling equipment. Such bearings consist of a shaft and upper and lower liners, which are provided with the holes for the feeding of lubricant fluid [1]. However, this type of bearings does not ensure the equal distribution of pressure of lubricating fluid on the surface of the shaft. Therefore, the author suggests two ways to solve the abovementioned problem.

Hydrostatic slide bearing

The basis of the hydrostatic slide bearing is the using of hydro layer as the lubricant fluid and accommodation the whole with opening for feeding of lubricant fluid in the top liner.

The developed hydrostatic slide bearing which has the similar features with the classic analogues such as the shaft, upper and lower linear has the hole with openings for feeding of lubricant fluid.

It is provided to locate additionally in the upper liner the hole and opening for feeding of lubricant fluid and two screws for closing the openings and at this the hydro layer is used as the lubricant fluid (in mass.

%) polyvinyl chloride resin of the trade mark M (20...10), dibutyl-phthalate(59...88), calcium stearate (0,5...1), vacuum oil (20,5…1), and the openings in the body and in the upper and lower liners have the inner thread.

Effect of combination of the cavity with a hole in the top liner with the using of hydro layer as the lubricant liquid to obtain the indicated technical result is that it provides the equal access of lubricating fluid across the whole surface of the shaft, and the use of hydro layer, as it is known from [2], is based on the principles of the third Pascal's law, according to which the pressure on the liquid, placed in a closed vessel, is transmitted simultaneously in all directions with equal strength.

Hydrostatic slide bearing (Fig. 1) is prepared for work so: before pouring of hydro layer 6 guide hydrostatic slide bearing is set on shaft 1 and heated to the temperature 120-160 degrees C.
After that, lubricating fluid, hydrolayer 6, is pumped through the hole 4; at first it gets to the top bearing liner with a cavity and hole for the feeding of lubricant fluid 2 and goes to the low linear of bearing with a cavity and hole for the feeding of lubricant fluid 3, simultaneously the hydrolayer 6 fills the space between the shaft 9 and surface of liners 2 and 3, and through the hole 4 the release from air of cavities of upper and lower liners 2 and 3. If the cavities of the upper and lower liners 2 and 3 are fully filled with the hydrolayer 6, the holes 4 and 5 are to be closed with the screws 7 and 8.

Hydrostatic slide bearing works so. The shaft 9 rotates creating efforts which, are felt by the lubricant fluid, hydroplast 6, which locates in the space between the shaft and the surfaces of liner 2 and 3 and in the cavities of liner 2 and 3. In the case of stationary (permanent) load to the hydrolayer 6 through the screws 7 and 8 according to the third Pascal law the equal distribution of the load will occur in the process of the work of the shaft 9 on the surfaces of upper and lower liners 2 and 3.

**Magnet slide bearing**

The base of the magnet slide bearing is the principle of using of magnets in the upper and lower liner and additional location of cavity with the hole in the upper liner for the feeding of lubricant fluid as well as the using of magnet lubricant as the lubricant fluid (in mass. %): magnetite – 30; oligoether – 40; diether carbon acid – 30.

It is provided to locate additionally the magnets in the upper and lower liners in the developed magnet slide bearing which has the similar features with the classic analogues (the body with the upper and lower liners and the cavity with holes for the feeding of lubricant fluid in the lower liner).
Also it is offered to locate in the upper liner the cavity with the holes for the feeding of the lubricant fluid and at this the magnet lubricant is used as the lubricant fluid, which components are given above. The influence of combination of location in the upper and lower liners of magnets, cavity with the hole in the upper liner with the using of magnet lubricant as the lubricant fluid for receiving the indicated technical result is based upon the fact that the equal access of the lubricant fluid on the whole surface of the shaft is provided due to the creation of the magnetic field. Because of location of magnets along the upper and lower liners the even magnetic field occurs which acts on the magnetic lubricant and enforce it to lean the surfaces of the shaft and evenly fill the radial gap. [4].

Magnetic slide bearing works so: before pooring the lubricant 8 the hydrostatic slide bearing is set on the shaft 6 (Fig. 2). After that the lubricant fluid, magnetic lubricant is pumped through the hole 4;

First it gets the upper liner of the bearing with the cavity and hole for the feeding of lubricant fluid 2 and then goes to the lower liner of the bearing with the cavity and hole for the feeding of lubricant fluid 3, simultaneously the space between the shaft 6 and magnets 7 is filled with the magnetic lubricant 8 and through the hole 4 the release of air of cavities of upper and
lower liners 2 and 3 is provided. If the cavities of upper and lower liners 2 and 3 are fully filled with the magnetic lubricant the holes 4 and 5 are closed with the screws 9 and 10. The shaft 6 rotates creating the efforts which are felt by the lubricant fluid, magnetic lubricant 8 which is located in the space between the shaft 6 and magnets 7 and in the holes of liners 2 and 3. The even distribution of the pressure of lubricant fluid, magnetic lubricant 8 on the surface of the shaft 6 is reached because of creation of the magnetic field by the magnets 7. Thus, during the rotation of the shaft 6 the magnetic lubricant 8 from the holes of the upper and lower liners of the bearing 2 and 3 by the magnet forces is pressed to the surface of the shaft 6 filling the whole space between the magnets 7 and shaft 6.

The mathematic working model of the machine installed on two slid bearings under the recommendations indicated in [5], can be presented so:

\[
\begin{align*}
Mh_t &= p_0 - p_1 \left( \frac{B(L + b)}{2} \right) - \mu \left( \frac{1}{4h} + \frac{1}{4h} + \frac{b \times (L - l)}{2} \right), \\
Q_0 &= \frac{p_0 \times h_0}{3\mu} \left( \frac{1}{B-b} + \frac{b}{L-l} \right) + \frac{V_{nL}}{E_s} \dot{p}_0 + h_0 (Bl + bl - 2bl), \\
Q_1 &= \frac{p_1 \times h_1}{3\mu} \left( \frac{1}{B-b} + \frac{b}{L-l} \right) + \frac{V_{nL}}{E_s} \dot{p}_1 + h_1 (Bl + bl - 2bl), \\
\dot{h} &= h_{tL} - h_t,
\end{align*}
\]

where \( M \) – given mass of spindle unit; \( h_0 \) and \( h_1 \) – gaps in left and right bearing units; \( p_0 \) and \( p_1 \) – pressure of fluid in the left and right bearing units; \( P_Z \) – external load; \( B, L \) – width and length of bearing supports; \( b, l \) – width and length of hydraulic hopper of support; \( \mu \) – dynamic viscosity of the liquid; \( V_{nL} \) – given volume of the hopper of bearing unit; \( E_s \) – module of the volume condensability of the fluid; \( h_{tL} = h_0 + h_1 \) – sum diameter gap in the system “shaft-bearing units”.

To simplify the analysis the linearization of nonlinear equations (1) is made by the spreading in Taylor row. Further it is convenient to make transformation of lineared system under Laplas going to operator form of the recording of equations and introducing the designation of coefficients and constants of the time.

As a result we get the mathematics model:

\[
\begin{align*}
[k_i(T_iS+1)] \cdot S \cdot \Delta h_t &= \Delta p_s + k_{\Delta p} \Delta p_s, \\
-k_{\Delta t} (T_iS+1) \Delta h_i &= k_{\Delta t} (T_iS+1) \Delta p_s, \\
-k_{\Delta t} (T_iS+1) \Delta h_{tL} &= k_{\Delta t} (T_iS+1) \Delta p_s, \\
\Delta h_i = -\Delta h_{tL},
\end{align*}
\]

where \( k_i \) and \( T_i \) – coefficients and constants of time; \( S \) – operator of differentiating.

The structural schemes of functioning of slide bearing units which correspond the system of equations (2) are given in the fig. 3.

So two methods of functioning of slide bearing are proposed in the article which give the opportunity to increase the reliability of work of rotating machines of oil and gas industry due to the even distribution of the pressure of the lubricant fluid on the shaft surface.

The developed mathematic models for the calculation of dynamic characteristics of slide bearings helped to define (fig. 4), that the gradient of change of value of the relevant displacement in the developed slide bearings of masses centre dependently of the degree of rotation of the shaft deviates in the range 5…8mcm which testifies the evenness of distribution of lubricant fluid on the shaft surface.
If the magnetic slide bearing is used (see fig. 2), the level of displacements of centre of masses is less than the indicators of hydrostatic slide bearing which is connected with more active action of the magnetic field on the magnetic lubricant.

Fig. 4. Results of mathematic modeling of relevant displacement of centre of masses of the bearing of the degree of rotation of the shaft at the frequency of rotation 1000 rev/min and loading 1500 H: 1 – traditional slide bearing with the lubricant fluid; 2 – developed hydrostatic slide bearing, lubricant fluid-hydrolayer; 3 – developed magnetic slide bearing, lubricant fluid – magnetic lubricant

As a result of the carried out investigations the working model of slide bearings is created and two patents for the useful model are registered.

The task of optimization of construction and technologic parameters of the developed bearing units can be resolved by means of development of the simulation model on the base of the received mathematic models.

The further plans are to conduct the experimental researches of work efficiency of such bearing constructions to develop the practical recommendations as for their implementation in the production process.

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OIL AND GAS TREATMENT

Methodically organizational principles of biological stability providing of aviation fuels

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The research of aviation fuels ability of biocontamination is performed, the mechanism of aviation fuels hydrocarbons destruction and consequences of this process is analysed. Determination methods of aviation fuels biological phase presence were researched. Efficiency of basic methods of biological stability providing of aviation fuels is studied. Methodically organizational principles of aviation fuels biological stability providing were determined.

Introduction

Property of microorganisms to metabolize hydrocarbons of solid, liquid and gaseous petroleum products was known in the early XX century. This phenomenon has become a cause of substantial problems in the field of oil producing, oil refining and petro chemistry, especially during exploitation of oil products [1–6].

From the one side, the change of oil and oil products properties under the influence of microorganisms finds application for the special aims (waste waters cleaning of oil-processing plants, cleaning of territories and aquatoriums from contamination by oil products). The other side, activity of microorganisms results destruction of oil products and the damage of materials and constructions that contact with them.

Therefore protecting of fuel lubricating materials from microbiological contamination is a very important problem. In a sphere of aviation fuel providing, development of microorganisms in fuels results deterioration of physical, chemical and operating properties because of their hydrocarbon composition change, accumulation of microbial mucus and sediment and formation of resistant emulsions. Clogging of aircraft filters and fuel pipes system by microbial mass leads to the aviation incidents and accidents [1–6].

Problem setting

Goal of the research is creation of methodically organizational principles of aviation fuels biological stability providing.

Object of research – biological contamination of aviation fuels and mechanism of hydrocarbons destruction.

Subject – methods of determination of microbiological contamination presence in aviation fuels and methods of its biological stability providing.

Based on actuality of this problem, the following tasks are selected for implementation of research:

1. The research of aviation fuels ability to biocontamination.
2. The research of aviation fuels hydrocarbons destruction mechanism and consequences of this process.
3. The research of methods that determine presence of biological contamination in aviation
fuels.

4. The research and efficiency analysis of major methods of aviation fuels biological stability proving.

**Problem solving**

During the creation of jet aviation in the USA, began active study of questions connected with microorganisms’ development in oil fuels. The work on this question in our country mainly was to determine fuels biostability in laboratory conditions. Purposeful researches of fuels biostability in exploitation conditions were not conducted practically.

There were not the generally accepted methods of fuels bio-contamination estimation to this time. For these purpose the well-known microbiological methods were used by which the presence of microorganisms in fuels, its quantitative content and specific composition were determined [3].

Because of absence of correct technological discipline the presence of fuel biodestructors is observed on the bottom of aviation fuels storage reservoirs, in the tanks of aircrafts, in deposits on filters [3].

Aviation fuels undergo biodamages during storage, transporting and exploitation. Especially unsteady to the biodamages fuels which are consumed by jet aviation [1, 4].

Significant factors that assist to active development of microorganisms are pH environments, presence of such elements as carbon, phosphorus, potassium, nitrogen, sulphur, iron, sun energy. There is also important an ambient temperature, so cells of microorganisms actively propagate oneself when the temperatures are 25–35 °C, although can grow when the temperatures vary from plus 5 to 45 °C. It is well-proven that the spores of many types of microorganisms remain viable during a few hours when the temperatures start from minus 40 °C [5].

There is also a necessary condition for development of microorganisms - presence of water and nutritives in a fuel [4]. The growth and development of microorganisms is stopped in the water-free fuel. However in the real exploitation conditions and fuels storage it is impossible fully get rid of moisture, and presence in fuel at least 0,01–0,02 % water and its tracks at the proper temperature is enough to begin growth of microorganisms. Today it is known [6] several sources of water ingress:

- atmospheric moisture from the air;
- rain or snow may fall into the tank through the holes for sampling, ventilation valves or untightly fitting lid;
- transportation or storage in tankers and on the boards can cause penetration of ballast water;
- water from all listed sources accumulated in the bottom of the tank, forming a water layer.

Microorganisms can penetrate to the fuel through air or water. Thus, during the water layer formation the colonies of microorganisms is developing. Liquid hydrocarbon fuel is an excellent source of nutrients for many types of present microorganisms. The result is a population “explosion”: microorganisms spread at the surface of fuel and water, begin to live in the water phase, continuing to eat fuel [7].

Today it is known 200 species of microorganisms, including 30 families that can use hydrocarbons as sole source of carbon and energy. These include bacteria, yeast and fungi. The most complete issue on destruction of hydrocarbons by microorganisms is reflected in works [1–6].
The main microorganisms, that cause biocontamination of fuels, are the next bacteria’s of family *Pseudomonas*, *Micrococcus*, *Mycobacterium*, family of fungi such as *Cladosporium*, *Aspergillus*, *Penicillium*, *Alternaria* and others, while in aviation fuels more often than in other petroleum products are bacteria *Ps.aerugenosa* and fungi *Cladosporium Resinae* («kerosene fungus») [1, 5]. The latest researches determined two more active bio destructors of aviation fuels *Hormoconis resinae* and *Monascus floridanbs* [7].

Microbial contamination such as *Cladosporium Resinae* consists of fibers that reach considerable length and form convoluted layer. Fungi reproduce by spores that may be in dormant condition long enough, waiting for growth favorable conditions. Fuel is often contaminated with microscopic fungi during transportation, storage, preparation and delivery, as well as in aircraft fuel tanks. Spores can remain undetected for considerable period of time because of mentioned above. Only in the case of favorable environment to their development, the spores germinate; fungi multiply and contaminate fuel [8].

It is proved that biocontamination of fuel is connected to microbiological enzymatic oxidation of hydrocarbons with formation of organic acids that have surface active properties [8]. The speed and depth of the microbial oxidation of aviation fuel depend on their carbohydrate composition. Hydrocarbons with a linear structure of the molecules are destroyed faster than their branched isomers. Aliphatic hydrocarbons (paraffin’s) are less biostable than aromatic. Therefore, fuels that contain mostly paraffin hydrocarbons can be destroyed by microorganisms faster than those containing more aromatic compounds [8].

The processes of microbial oxidation of hydrocarbons are very complex, because the processes of biogenic oxidation have an influence of many factors: moisture, environment acidity (pH), temperature, osmotic pressure, and so on. In addition to these factors are important physiological characteristics of most microorganisms that occur during the oxidation of individual hydrocarbons and their mixtures [7, 8].

Microorganisms have the selective ability related to various hydrocarbons, and this ability is determined not only by the difference in the structure of substance, and even the number of carbon atoms that are the part of their structure.

Hydrophobic of hydrocarbon molecules is important for the chemistry of microbial oxidation of these compounds, their transport in the microbial cell and dynamics of reproduction and physiology of bio destructors.

The first stable products of hydrocarbons oxidation are the primary alcohols. The next is usual biological conversion of alcohols to aldehydes and aldehyde to acid. The general scheme of reactions [7]:

\[
R-\text{СН}_2\text{CH}_3+[O] \rightarrow R-\text{CH}_2\text{CH}_2\text{OH}-2\text{H} \rightarrow \\
\rightarrow R-\text{CH}_2\text{CHO}-2\text{H}+\text{HOH} \rightarrow R-\text{CH}_2\text{-COOH}.
\]

Reduced paraffin fuel capacity by biochemical oxidation occurs due to removal of model systems of n-alkanes as substances which mainly consume microorganisms.

From the physiological characteristics of each kind of microorganism depends orientation process of individual hydrocarbons destruction and their mixtures that have different degrees of resistance to oxidation.

Research of the microorganisms’ ability to oxidize specific classes of hydrocarbons within the aviation fuels, allows in perspective to create biologics for specific purposes.

After the damage of fuel by microorganisms in the presence of the mentioned above favorable conditions the next consequences are observed [1–7, 9]:

- *change in physical and chemical properties of fuels*, namely increasing of major physical
and chemical parameters values as kinematic viscosity, refractive index, pH, content of actual res- ins and others. Also characteristic features are the formation of sediment, turbidity fuel and peculiar odor;

- **corrosion of storage tanks for aviation fuels.** Corrosion development of bottom part where accumulates water sludge, especially on verge of system distribution «fuel-water», corrosive damage of aircraft tanks, corrosion of aircraft power con- structions;

- **clogging and damage of fuel filters, pumps and fuel systems.** Sedimentation of mycelium and bacteria colonies at the inner walls of the fuel systems leads to clogging of pipelines, filters, pumps and fuel systems;

- **threat to the safety of aircrafts flights.** Changing the physi- cal, chemical and exploitation properties of aviation fuels leads to early clogging of filters, pollution of regulating equipment, causing unstable operation of the fuel system, and therefore can cause failure of the engine, and even complete failure of the system, and as a consequences – appearance of accidents and emergency landings. [3]

Methods for detection of microbiological contamination of fuels are divided into long-term and express methods [2]. The long-term methods include seeding of microorganisms in nutritive environment followed by microscopic analy- sis of cultivated cultures. Express methods used in airport. They are based on indication of microorganisms by chemi- cal compounds. One of these methods is determining micro bial contamination of fuels for jet engines with a solution of ninhydrin. Ninhydrin - organic compound belonging to the classes of ketones, alcohols and condensed carbocycles used as qualitative and quantitative reagent in the determination of primary amines and amino acids.

In this area there are patented detection techniques of bio contamination in aviation fuels with using two sets Microb- Monitor 2, Hum Bug Detector, Bug Alert, Bug Check, electronic meter HMB IV.

For example, when using MicrobMonitor 2 test results are available within three days and do not require further interpre- tation [9].

Exploitation practice shows that in areas where the risk of getting fuel contamination are higher, the frequency of che- cking for microbiological contamination presence should be at least once a month.

Methods for preventing microbiological contamination of aviation fuels are divided into active and passive [1–4].
Passive methods include the range of activities related to plants of aviation fuels providing, that can reduce fuels biocontamination.

Active methods include adding to fuel biocides – antimicrobial additives.

Exploitation protective methods are the following:
- proper fuels storage conditions;
- regular drying and removing of water (sludge) from the tanks bottom, filters, fuel tanks, aircraft tanks;
- avoiding of contact with water and atmospheric moisture, reducing contact with air, especially humid;
- timely cleaning of technological equipment of fuels storage;
- filtration.

There are many ways to prevent biological contamination of fuels. One of such method is the method of ultraviolet and electromagnetic radiation. Ultraviolet radiation causes the death of microorganisms. For this purpose the UV lamp was developed. During its development excluded the possibility of explosion and inflammation of fuels. The lamp can be mounted to the bottom of the fuel tank and move along it, as well as along the fuel line.

Possible installation of lamps during pumping fuel from one tank to another. Destruction of microorganisms is also possible by using electromagnetic radiation at a certain frequency radio waves [4]. Colonies of fungi and bacteria can be removed by filtration through a porous material, the pore size of which is not more than 2 microns. Possible way to protect the fuel through bacterial filters, filled with silver compounds – cotton, glass, synthetic rubber.

To physical and mechanical methods of microbiological contamination control are also include centrifugation followed by agglomeration filtration, flotation, the use of ion-exchange resins, electro hydraulic deposition, ultrasonic control [4].

The most effective way to protect the fuel from biological contamination at present is biocide additives that reduce activity of microorganisms in jet fuels and prevent biological corrosion of fuel tanks [1, 5].

During the choosing of biocide additives there are the following requirements: they must not impair quality of fuels, characterized by prolonged action, detrimental effect on engine structural parts, fuel regulatory apparatus, reliability of filters and filter separators, to be toxic. Combustion products of these substances should not cause adverse effects on the environment [4].

Biocide additives may be soluble in fuels, and water cushion and destroy microorganisms in both phases [4, 5].

Many biocide products have been tested abroad that meet the above requirements, there are the following: ethyleneglycol monomethyl ether and Biofora F [4].

Ethyleneglycol monomethyl ether – is anti water crystallization additive, with glycerol. However, it was found that glycerol actively contributes to the microorganisms, and without it ethyleneglycol monomethyl ether reduces their growth. In addition to the fuel for air jet engines – 0,1-0,15 % by weight, substance concentrates in water up to 20%, which not only prevents the formation of ice crystals, but also reproduction of microorganisms.

Biofor F after the penetration to oil product is concentrated in the free water. The mechanism of this substance action is also based on increasing of osmotic pressure. The effectiveness of the substance is in its lower concentrations in the water. This additive has the
following drawback: when added to jet fuel is deposited on the blades of aircraft turbines and can cause them to corrosion due to increased acidity of water.

Long-term monitoring of fuel tanks coated with furan resins showed that microorganisms in these tanks is reduced [4]. There is well-known antiwater crystallization liquid «I-M», which is a product of association ethyl cellosolve and methanol. Liquid «I-M» is designated for use as additives to the fuel for the air jet engines, refueled aircrafts of civil aviation to decrease the probability of icing aircrafts and heli-copters filters at low temperatures. We researched bactericidal properties of the additive that caused by containing of methanol [10].

There are used biocides that have the active components – cellosolve, compounds of nickel, copper and other metals, heterocyclic compounds in quantities 0,0001-0,005% [7].

Due to increasing the range of biocide additives, there were studied bactericidal activity of such compounds dimethyl- dialkyl-ammonium chloride ([R2(CH3)2N]Cl) and dimethyl- alkyl-benzyl-ammonium chloride ([R(CH3)2NC6H5–CH2]Cl) for aviation fuels - gasoline and fuel TS-1 for air jet engines [8].

During the study of these compounds has been established [8] that the amount of 0.05% or more above mentioned additives reduce the growth of all microorganisms in the aviation gasoline and fuel TS-1.

It was studied biocide activity of such compounds: zinc salts of synthetic fatty acids, mixed salts of zinc and mercury, acetic and oleic acids. With addition to jet fuel in concentrations of 0,05–0,1 %, they found sufficient activity, reducing the number of microorganisms on 75–85 %. The salts of higher carboxylic acids of chrome, copper and lead, and also naphthenate of iron, copper and chromium were low-toxic [3–5, 11]. Taking into account problem actuality of protection from both fuels accumulation of static electricity, and from microbiological contamination, was obtained complex additive that has antibacterial and anti-static properties. Mixtures of bactericidal and anti-static additives of different composition were studied; both bactericidal components applied dimethyl-dialkyl-ammonium chloride [8]. Simultaneously, this additive is an effective anti-static additive in concentration of 0,003%, increases conductivity and reduces oil electrification during their motion [8].

It is set that the antiwater-crystallization additive PFA-55MB has high bactericidal effect for jet engines. Addition to jet fuel in an amount of 0,05–0,15 % of PFA-55MB additive practically fully prevents development of microorganisms and corrosion of fuel tanks of jet engines. This additive is the most widespread abroad [9].

It was found that 8-hydroxyquinoline and disalicylidenpro-pandiamin in addition to fuel for air jet engines brand TS-1 in concentration 0,2 and 0,1 % diminished growth of microorganisms accordingly on 88 and 75 %. Primary amines of C12–C15, which was added to the fuel in an amount of 1%, diminished growth of microorganisms on 95 %.

Special experiments [1, 2] reflected that active biocide additives in the water-fuels systems there can be substances that do not dissolve in fuel, but soluble in water. Thus, the complete destruction of microorganisms in the environment in fuel TS-1 was observed when injected into the water phase one of the following substances: 0,04% 1,2-diaminopropano or hexamethyldiamin, 0,12 % ethylenediamin, hydroxylamine of hydrochloric acid or methylamine tartrate, 0,16 % trimethyl-amine or n-butylamine.

Growth of microorganisms reducing on 98% is observed when the content in the water phase 0,08 % n-butylamine, ethylendyamina, hydroxylamine hydrochloride or methylamine oxalic acid.
Inhibition of microorganisms increasing by 70, 75 and 90 % was observed in environment of fuel TS-1 when in the water phase added respectively 0,24 % chromium acetate, 0,16 % chromium nitrate, 0,16 % copper acetate [9, 10].

There is also known multifunctional additive IPOD (iso-propyloktadetsylamin).

Bacteria fungicidity of additive on the base of gas condensates was studied. Unlike the other additives, it obtained from hydrocarbon fractions (145–280) °C of gas condensates. Adding of the additive in amount of 0,1% destroyed microorganisms within 10–15 days on 100 % [5].

Synthesized additive has not only antibacterial, but also antioxidant and anti-corrosion properties. The additive addition to final concentration of 0,1 % prevents sediments in fuel on 80 % [5].

Katon FP 1.5 of the company ROHM AND HAAS (U.S.A.) is one of the highly effective biocides that used worldwide for various fuels. In the nomenclature of the International Union of Theoretical and Applied Chemistry, an active component of Ka-ton FP 1.5 is defined as 5-chloro-2-methyl-4-isotyazolin-3-one. Today many foreign companies are producing biocide additives to petroleum products, such as: «Bang and Bonsomer»,

«THOR», «ROHM AND HAAS» and others [3].

The authors conducted research on the efficiency of modern biocide additives (applications) of mentioned above foreign manufacturers. The research was conducted by the method of diffusion zone, which is testing the microbiological stability of jet fuel protected by antimicrobial additives with different concentrations in the Petri dish on nutrient dry agar for cultivation of microorganisms. Zones diameter of growth absence characterized the degree of test fuel stability.

It was used a mixture of aerobic bacteria (Pseudomonas, Bacterium, Mycobacterium) as a test cultures, allocated from the affected oil.

Table

<table>
<thead>
<tr>
<th>Additive name</th>
<th>Zone diameter, mm</th>
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<tbody>
<tr>
<td></td>
<td>Additive concentration in fuel RT</td>
</tr>
<tr>
<td></td>
<td>1 %</td>
</tr>
<tr>
<td>Formacide</td>
<td>0</td>
</tr>
<tr>
<td>KATHON</td>
<td>0</td>
</tr>
<tr>
<td>Grotan F10</td>
<td>25</td>
</tr>
<tr>
<td>Grotan OX</td>
<td>0</td>
</tr>
<tr>
<td>Grotan TK 6</td>
<td>0</td>
</tr>
<tr>
<td>ACTICIDE KL</td>
<td>16</td>
</tr>
<tr>
<td>ACTICIDE OX</td>
<td>36</td>
</tr>
<tr>
<td>Pure fuel RT (control)</td>
<td>0</td>
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</table>

The research results of biological stability of aviation fuel RT, protected by biocide additives with the method of diffusion zone are shown in Table.

So, our diagram represents that the best antimicrobial properties has the following additives: GROTAN OX, AKTI-CIDE OX, AKTICIDE MV14.

Conclusions

Analysis of the aviation fuels ability to bio contamination and studying the mechanism of hydrocarbons degradation showed that, along with hydration and fuel pollution by mechanical impurities occurs microbiological contamination that affects not only fuels quality, but also on the exploitation reliability of the equipment.
Research methods for determining the presence of biologi- cal contamination in aviation fuel has shown that the appea- rance and development of biocoenosis in fuels lead to deterioration of their physical, chemical and exploitation properties due to changes in their hydrocarbon composition, accumulation of microbial slime and sludge formation of stable emulsions. The best method of microorganisms detecting in operational of air- field is to use indicator express methods.

Among the variety of protection methods of microorga- nisms was found that the most effective method of protecting aviation fuels from microbiological contamination is the use of antimicrobial (biocide) additives.

International practice of biocide protection from micro- organisms in aviation fuel is efficient enough, but it does not apply in the countries of CIS because of the high cost of reagents and absence of recommendations for their use in the regulatory framework.

Scientific interest is the development of express methods that determine the microbiological contamination presence in airfield operational conditions and domestic biocide additive that will substantially reduce the degree of microbial destruction of aviation fuels.

References
V.I. Styopkin is 90 years old.

Vasyl Ivanovych Styopkin, the famous specialist of the branch was 90 years old on 14th of January 2013. He was born in 1923 in Georgiyivsk, Stvropol region (Russia). In 1940 he entered the industrial faculty of Grozny Oil Institute. In 1941-1945 he participated in acting army, he finished the war with the rank of senior leutenant. He was wounded seriously in the battles near Feodosia, he had cured for a long time. After demobilization he continued studying in the Institute from which he graduated in 1950.

He started working on Mongolia passing the way from a master to the main engineer of the drilling office. From 1954 he worked the head of production and technique department of Nadvirnyansky KB and in three years he was appointed the main engineer of Dolynska KB NPU “Dolynanafta”. In 1960-1963 he had a position of the main engineer of trust “Prykarpaturnafta”

With the participation of Vasyl Ivanovych in the drilling enterprises of Prykarpattia the simultaneous drilling of two wells from one drilling machine on Dolynska bed for the first time, as well as the using of diamond bits, introduction of systems of mechanization of drilling works and other innovation decisions.

In 1964-1969 he was a deputy head of the contract of soviet specialists of the investigation of oil and gas in Germany. The drilling works were successfully operated at his management, the new gas beds were disclosed, and in particular, the open gas fontane was liquidated promptly on one of them.

After returning from business trip V.I. Styo pkin worked as a Head of department of the testing of wells, and then a head of technical department of Golovnaftogazrozvidka of Ministry of Geology of Ukraine. In 1972 he was appointed a Deputy Minister of geology, responsible for drilling of the wells. He worked at this post till the retirement in 1984.

In this period the enterprises of Ministry of geology annually drilled 500-600 thousand m. of wells, disclosed new oil and gas beds. As the construction of investigating wells was made in difficult geological conditions, in particular in conditions of abnormally high pressures Vasyl Ivanovych paid much attention to the modernization of technique and technology of drilling, quality of washing liquids, preventing the accidents, and in particular open gas fontanes. Due to the using at large depths of turbine drilling including high-output turbo-drills, new constructions of bits as well as the moving to the drilling of the wells of decreased diameter, it was achieved to increase significantly the technical and economic indicators of geologic and investigating works.

He weared the unchanged canvas coat and tarpaulin boots and was present almost at each fontane or the development, hurring there directly after the train and “puddled a swamp” at the drilling spot the same as the others. Under his surveillance the whole pleiad of high-qualified technologists and chiefs of of drilling works emerged: B.O.Byaluk, O.O.Voloshyn, S.M.Gnida, B.I.Golodyko, M.I.Lysyi, B.M.Moscalenko, V.S. Ovcharenko, R.M.Seniv, V.M.Stefanyshyn.

Vasyl Ivanovych has battle and labor awards: orders of Patriotic War of I and II deg., Labour Red Flag, “Motherland merits” (NDR), medals “For victory over Germany”, “For heroism in difficult situation” (NDR), gratitudes of Supreme Commander-in-Chief and others. He is a laureate of State Award RM SRSR.

Today V.I. Styopkin cheerfully tapping the computer for one moment can find the history of some fontane or other remarkable event.

We wish to Vasyl Ivanovych good health, well-being and long life.
Colleagues, the editors of journal

NON-TRADITIONAL TECHNOLOGIES AND ENERGY EFFICIENCY

Some methods of upgrading of technologies of construction of wells for shale gas

УДК 622.24

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Based on the analysis of international practices the directions for improvement of the construction technologies for shale gas wells are worded. Particular attention is paid to the quality of the well construction, technologies of drilling-in and development of a payout beds.

According to expert assessments [1–3], the significant (more than 1,1 billion m$^3$) stocks of shale gas are concentrated on the territory of Ukraine and this opens the opportunities of replenishment of energetic resources at the cost of own gas mining. Shale gas belongs mainly to the diffuse gas in the pore -crack cavities connected with the peculiarities of layering pelitomorphic shale formations, including gas of closed pores and sorbed by mineral and organic substances, occasional to the low permeable reservoirs and causes the low yields of boreholes [2].

Today in Ukraine there is no experience of construction of wells for shale gas. Therefore it is important to study and generate the world experience, that gives an opportunity to improve the technologies of construction of wells.

The analysis of world experience of well construction Specific features of the production of shale gas require the use of technologies of well drilling, aimed for improving of their performance. Construction of shale gas wells is performed with the using of the technologies of drilling horizontal bores and intensification of gas - using the multiphase hydraulic fracturing) (HF)[3-5].

Experience in the construction of wells in the Barnett, Woodford, Haynesville, Bakken, Fayetteville and other wells[3, 4] demonstrates that each shale gas well requires its own technology of development. This is due to the peculiarities of geological structure of the wells, properties of rocks and different nature of gas storage. On Fig. 1 the basic problems in drilling wells for shale gas are systematized. For drilling of horizontal bores the drilling muds on water and oil base are used. The horizontal bores are mainly fixed by the casing columns and cemented. On the bed Bakken the boreholes are finished by the open bore or uncemented stem, on the wbed Fayetteville the tendency of open finishing of wells using cuffs and packers is also observed [4].
In [5] to intensify coming of gas the HF is considered using the technological liquids on the base of propan.

In [6, 7] the technology of guided coiled tubing drilling of horizontal bores is recommended in the conditions of depression for payout bed. It is so called technology UBD (underbalanced drilling). Such a technology is a prospective and has a raw of advantages, in particular:

- increase of mechanical boring speed;
- prevention of pollution of the payout bed;
- estimation of parameters of the the payout bed at real time mode through the use of a cable channel of communication and systems of directional drilling;
- the possibility of passing of the wellbore in beds of small thickness and other.

For creation of depression in some case it is efficient to apply the nitrogen units of cryogenic type.

Coil tubing technologies are successfully applied for the intensification of gas production through technology RDS or radial drilling (company «Radial Drilling Services, Inc.», USA) and HF.

**System of estimation of wells quality**

The base of the structure of the management of quality of the facilities of oil and gas wells suppose the concept of quality and system of its evaluation [8]. A set of parameters, characterizing the oil and gas borehole from the position of fulfilling the main requirements in accordance with the project of development of the bed determines the quality of the well as the engineering structure.

In the general case, the quality of the well should be evaluated according the flexible hierarchical structure of criteria, depending on the purpose and trajectory of the well, kind and mining and geological drilling conditions and other factors. The upper level of the hierarchical structure should include criteria that characterize the trajectories of the well, its fixing, opening of productive horizons, as well as the environmental requirements.

**Criteria of well quality**

<table>
<thead>
<tr>
<th>Geophysical</th>
<th>Technological</th>
<th>Ecological</th>
<th>Others</th>
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<tbody>
<tr>
<td>Assessment of resources of shale gas</td>
<td>Construction of adequate hydrodynamic models of bed</td>
<td>Construction of large number of wells</td>
<td>Preparing of highly qualified personnel for realization of innovating technologies</td>
</tr>
<tr>
<td>Studying of physical and mechanical collector properties of mine rocks in natural state</td>
<td>Choice of scheme of placement of wells and their shafts</td>
<td>Using of technologies of intensification of mining</td>
<td>Social</td>
</tr>
<tr>
<td>Construction of geological model of bed</td>
<td>Achievement of high quality of wells construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Studying of processes of cracks creation, their monitoring during FHF</td>
<td>Drilling of horizontal shafts in the producing formation</td>
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</table>
There was proposed the open hierarchical structure of criteria of the quality of oil and gas wells, which allows their possible additions and exclusions on different levels of the hierarchy (Fig. 2). This will ensure more accurate assessment of the quality of drill depending on its purpose and peculiarities. Geometric criteria assess the quality of the well according its trajectory to the design statement.

**Criteria of fixing** assess the reliability of fastening (readiness, reliability, maintainability) of well as the technical structure from the positions of the execution of its functional tasks. The assessment of the quality of the well under the criteria of fixing may be performed separately for casing column (including wellhead and downhole equipment) and separation of beds.

**Criteria of drilling of productive beds** assess the effectiveness of technology completion of the wells concerning the preservation of reservoir properties.

**Ecologic criteria** assess the quality of the well according the indicators of protection of subsoil and environmental protection. In the general case, the structure of environmental criteria is complicated, which is caused by the different character of environmental pollution. Its choice depends on the location of the well and the current system of environmental monitoring.

A system of criteria and principles for quality assessment can be implemented during the stages of design and construction the of wells [8], which gives the opportunity to formulate increased requirements to the projects in order to achieve a high quality of well construction. Principles of evaluation of quality of technologic operations.

At last the quality of the well depends on the list and sequence of technological processes, the compliance of their parameters with drilling and geological conditions etc. Thus, targeted control and management of technological processes is an integral part of the system of management of quality of well construction.

Technologies of deepening and completing of the wells are given by the relevant combinations of the basic operations. Each operation is characterized by a set of relevant parameters and system of specific restrictions on the parameters defining the quality of the operation.

In general, the assessment of the quality of technological operations is to identify the main and controlled parameters, forming of system of restrictions under the terms of the safe drilling operations, and ensuring the quality of the construction of the well, the rationale for the criterion of optimality and parameters of operations [8].

### Criteria of well quality

<table>
<thead>
<tr>
<th>Geometric criteria of well</th>
<th>Criteria of fixing of well</th>
<th>Criteria of exposure of producing formations</th>
<th>Ecological criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates of clearing</td>
<td>Casing string</td>
<td>Type and properties of drilling mud</td>
<td>Protection of depths</td>
</tr>
<tr>
<td>Intensity of curvature</td>
<td>Solidity</td>
<td>Hydrodynamic conditions (repression)</td>
<td>Environmental protection</td>
</tr>
<tr>
<td>Trajectory of exposure of productive formation</td>
<td>Containment</td>
<td>Degree of placement of cement slurry on the depth</td>
<td>Time of exposure of productive formations</td>
</tr>
</tbody>
</table>
The efficiency of the technological operations of deepening of wells is defined by the criteria which correspond the minimum cost of construction of the wells. Criteria of efficiency of technological operations of completion of wells should be aimed at increasing the quality of the opening of productive horizons and reliability of the well as a technical facility.

System of assessment of quality of construction technologies of the wells should include the standards on the execution of each technological operation for the relevant drilling conditions. Standards should contain recommendations on the choice of values of parameters, monitoring and analysis and modification of the technological operation with the purpose of increase of its quality. Parameters of technological operations $x = (x_1, x_2, ... x_n)^T$ are chosen of conditions for safe drilling operations, execution of restrictions $\varphi(x)$ to ensure the quality of the well and the optimality of criterion $K_I(x, a)$ of the effectiveness

$$K_I(x, a) \rightarrow \min, \; l \in L, \; x \in D;$$
$$\varphi(x) \leq 0,$$

where $D$ – sphere of defining of parameters of technologic operations; $a = (a_1, a_2, ... a_m)^T$ – vector of model parameters.

So at the base of abovementioned we can propose 4 score system of assessment of the quality of technologic operations:
Very high – parameters of technologic operations correspond the adopted system of restrictions and grounded criterion of optimality;

*high* - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the grounded criterion of optimality;

*satisfactory* - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the limits of ensuring the quality of the facilities of the well;

*unsatisfactory* - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the conditions of safe conducting of drilling operations.

**Technologies of drilling of productive beds**

Preservation of the natural permeability of productive beds is an essential requirement to technology of completion of wells. Its efficient solution influences on the performance of the wells and the degree of extraction of carbohydrates in the process of developing of beds. Prevention of pollution of the productive bed requires a comprehensive and detailed approach to the resolving, and is based on the scientific basis. In general the methods of prevention of pollution of the productive bed cover the choice of the well design, technologies of initial and secondary drilling of the bed, the choice of drilling mud system, control of hydro- and thermodynamic conditions of drilling of the bed [9]. The choice of design of the well and implementation of each technological operation at the stage of its completion should be subject to the requirements of the qualitative drilling of productive horizons.
The most reliable technologies for the prevention of pollution of productive of the world. It has been proved that the potential of technologies of wells completion can be achieved only during the drilling of the horizons UBD (with a detachable differential pressure) [10].

where \( p_j(z_P) \) – hydrodynamic pressure in the well at the depth \( z_P \) of productive bed during the execution \( j \) of technological operation; \( \Delta p_{\text{max}} \) – maximum acceptable repression on the bed (for example, during the drilling process of the bed at maximum acceptable repression on the bed).
System for the analysis of rheological properties is intended for processing data of the rotational viscosity of drilling technological liquids, built on a strict solution of the basic equation of rotational viscosity and takes into account the information richness of experiences [11]. Class of rheologically stationary models includes common models in drilling practice of Newton, Shvedov-Bingam, Ostwald, Gershe La Balkli, Shulman-Caisson, and biviscous models like

\[
\dot{\gamma} = \begin{cases} 
\dot{\gamma}(\tau, a^{(1)}) & \tau \leq \tau^*; \\
\dot{\gamma}(\tau, a^{(2)}) & \tau > \tau^*, 
\end{cases}
\]

where \(a^{(1)}, a^{(2)}\) – rheological model properties for low and high gradients of rates of fault; \(\tau^*\) – border tension of fault which is defined after the resolving of equation \(\dot{\gamma}(\tau, a^{(1)})=\dot{\gamma}(\tau, a^{(2)})\).

The system allows the construction of adequate assessments of rheological models and properties, the matrix of covariances of assessments of rheological properties, batch processing array data, construction of barothermic and other equations of state of rheological properties. It is important for modeling of hydrodynamic processes (assessment of external capacity of drilling fluids [12], managing of hydrodynamic conditions (2) and others) to make effective technological decisions. The functionality of the system surpasses the well-known analogues.

The system of choosing of optimal formulations of drilling solutions is constructed using the model of the form (1) [13].

\[
\begin{align*}
E(x^v) & \rightarrow \min, v \in \partial, x^v \in D^v; \\
\varphi(x^v) & \leq 0,
\end{align*}
\]

where \(E(x^v)\) – criterion of optimality; \(x^v\) – vector of concentrations of reagents of \(V\) component composition; \(V\) – class of acceptable sets of reagents; \(D^v\) – area of determination of vector \(x^v\); \(\varphi(x^v)\) – system of restrictions for concentrations of reagents.

The peculiarity of the model (3) is a preliminary choice of local criterion \(E(x^v)\) of optimality of some set of possible ones, which corresponds the global criterion the best for the given conditions of drilling. Depending on the conditions of exposure of the productive bed, it is possible to use the various criteria of optimality: the cost of a volume unit of drilling mud, corresponding of certain indicators of the properties to the specified values, the external ability of flow of mud in the given interval of the well, relative decrease in the permeability of the core material, etc. Information support of model (3) is based on the results of experimental studies according the relevant plans.

For disclosure of low-penetrating productive beds [13] advises to conduct a two-stage procedure of choice of drilling mud. At the first stage, the basic formulations are to be chosen of the provision of the minimum value, and at the second - the optimal formulation of mud on the criterion of minimum interfacial tension on the border of phases mud filtrate - fluid. The decision making support system is created, which allows a free choice of the criterion of optimality and system of limitations, design, and maintenance of plans of experiments, the interpretation of their results, the search for optimal formulation of drilling mud. This system can be used to select the optimum recipe of processing of drilling mud in the process of well drilling.

**Well development technologies**

Well development resolves into the calling of the fluid flow, cleaning of the bottomhole formation zone of mud filtrate and other polluting adds, carrying out of the necessary works in
order to increase the filtration characteristics of the bed and commissioning of the well. Parameters of all technological operations during the well development should meet the requirements of quality according (1). Technological liquids for development of wells should be selected using the model of the appearance (3).

To develop the shale wells with hydraulic fracturing the technologies of «EMPI - service» Ltd. can be effectively used which allow the implementation of the necessary technological processes for one using of set of tools with ejector pumps UGIS of series 11-20, 31-40 and 41-50 [14, 15], in particular: industrial-geophysical and hydrodynamic investigations of the hydraulic fracturing; HF through the ejector pump UGIS; removing of the working fluid HF and propant from the bed through UGIS;

Repeated industrial-geophysical and hydrodynamic investigations.

Fig. 4. Scheme of components of well equipment during the operation of gas well with the help of ejector pump НЕД-1В: 

а – installation of two-raw lift with the body НЕД-1В;

б – removing of liquid with the help of НЕД-1В

The technologies are used in the vertical and bent guided wells combining with coil tubing equipment. [14, 15].

Fig. 3 shows the scheme of components of the tool with the ejector pumps UGIS-(31–40)Ш for research and development of the well with abnormal low bed pressures (ALBP) with the help of HF. Here different detachable ejector devices are used with one body, as well as the reverse (fig. 3, в and г) and direct (fig. 3, а and б) circulation of liquids.

For exploitation of methane-coal and shale wells with ALBP the design of the plug-jet pumps НЕД-1В [16] is developed, which is used with two-line arrangement of pump-compressor pipes with a diameter of 48 and 89 mm. Ejector pumps НЕД -1В have high operational reliability in the presence of gas and mechanic impurities in the fluid, replacement of jet couples does not require the use of teams for overhauling of wells and cable equipment. Fig. 4 shows the diagram of the components of the well equipment for operation of gas wells with ALBP using the injector pump НЕД -1В. Technical water can be used as a working agent. To provide the technological requirements of operating gascompressor stations the scheme of components includes the use of two-raw lift on the entire length of the well. The scheme of
components can be applied subject to free curvature of the wellbore.

Technologies of “EMOI-service” Ltd. with the using of ejector pumps UGIS are used at the beds of Russia [14, 15]. Ejector pump НЕД-1В has been successfully tested at methane and coil wells of Russian Federation.

At the base of mentioned in the article we can refer to the possible vectors of improvement of construction technologies of the wells for shale gas as follows:

- system of assessment of quality of well construction;
- system of assessment of quality of technological operations;
- technologies preventing the pollution of productive beds due to the choice of properties of technological liquids and guidance of hydrodynamic situation in the well;
- multifunctional ejector layouts and technologies of development and operation of the wells.

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PROTECTION OF LABOR AND ENVIRONMENT

Upgrading of technology of absorptive cleaning of oily wastewaters

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УДК 628.316.12:665.71 (045)

*Oily wastewater treatment technology is improved through the improvement of the absorptive properties of sorbents based on plant waste. The cost of flowsheets for treatment of wastewaters contaminated with oil products is presented.*

Almost all enterprises of oil and gas complex face the problems connected with the cleaning of oily wastewaters. The State International airport (SIA) “Kyiv” (Zhulyany) of oil products is not an exception. Old and nonefficient cleaning equipment does not provide the cleaning of wastewaters to the alarm concentration 0,05 mg/l [1] (Table 1).

**Efficiency of wastewaters cleaning by the treatment facilities of the airport**

<table>
<thead>
<tr>
<th>Before cleaning mg/l</th>
<th>After cleaning mg/l</th>
<th>Level of cleaning, Y,%</th>
<th>Alarm concentration, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,880</td>
<td>0,592</td>
<td>68,5</td>
<td>0,05</td>
</tr>
</tbody>
</table>

In general case during the selection of cleaning technology of particular wastewater the determining factors are the consumption of wastewater, outlet concentration of oil products and concomitant contaminations, demands for the quality of cleaned water on all contaminations which are regulated. It is worth to note the oily wastewaters undergo changes from the place of formation to the place of treatment facilities which significantly worthens and complicates the treatment process. Thus, depending the demands of quality of treated water as well as the whole row of technical and economic indicators the technologic system of treatment can be chosen, which base is the mechanic treatment. During the development of flowsheet except the polycomponent composition wastewaters it is worth to consider phase disperse state and level of aggregate resistance of oil products. During the selection of technical system it is worth to avoid the using of intermediate transferring of oily wastewaters to prevent additional emulsification of oil products. Therefore the using of free-flow treatment systems is more rational.

The aim of our scientific researches is the upgrading of treatment technology of oily wastewaters with use of sorbents on the base of plant raw material at the example SIA “Kyiv” Zhulyany.

![Fig.1. Upgraded flowsheet of treatment facilities SIA “Kyiv”](image)

1 – sand-catchers; 2 – clarifiers of hung substances (silt);
3 – oil-catchers; 4, 5, 6, 7 – pools for additional cleaning of oil products by sorbent on the base of sawdust; 8 – collector
Reliable and qualitative treatment of oily wastewaters is possible only while the realization of multistage flowsheets of removing of oil products.

On the base of results of the performed complex researches [2–4] we proposed the upgrading of treatment technology of wastewaters contaminated with oil products. The proposed technologic system must be composed of three stages (Fig.1). At the first stage the mechanical treatment is provided in the case of high concentration of oil products (classic sand-catchers (1), clarifiers (2) and oil-catchers (3)), at medium concentration – depth treatment by non-treated absorptive materials of vegetable matter (which are wastes nowadays) – sawdust or sunflower peeling (pools 4 and 5) (tab. 2) and at third – with treated at the temperature 200 °C (pools 6 and 7) (tab. 3). For the thermal treatment of sorbents on the base of vegetable raw in the laboratory conditions the chamber laboratory electric oven was used СНОЛ 7,2/1100; in the industrial conditions system SNOL 2250/500.

Table 2

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Before treatment, mg/l</th>
<th>After treatment, mg/l</th>
<th>Level of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawdust</td>
<td>1,880</td>
<td>1,720</td>
<td>8,5</td>
</tr>
<tr>
<td>Sunflower peeling</td>
<td>1,880</td>
<td>1,516</td>
<td>19,4</td>
</tr>
</tbody>
</table>

Fig. 2. Expenses for treatment of contaminated wastewaters to the alarm concentration by the treated under different temperature modes under the technologic scheme 4: a - sawdust b – sunflower peeling

Table 3 Efficiency of oily wastewaters by sorbents on the base of sawdust and sunflower peeling

<table>
<thead>
<tr>
<th>Fraction size, mm</th>
<th>Treatment parameters</th>
<th>Outlet of</th>
<th>After treatment, mg/l</th>
<th>Degree of treatment Y, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time effect, min</td>
<td>sorbent B, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>temperature Т, ºС</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3</td>
<td>20</td>
<td>200</td>
<td>89,5</td>
<td>0,932</td>
</tr>
<tr>
<td>Sunflower peeling</td>
<td>10</td>
<td>200</td>
<td>87,6</td>
<td>0,812</td>
</tr>
</tbody>
</table>

Applying of sandcatchers provide the initial detachment of suspended substances of mineral origin as a result of gravitation power. Then wastewaters go to clarifiers where the main part of
organic hung substances are settled to the bottom. At the last stage of the mechanical treatment the deparation of water and oil occurs in oil catchers because if the difference of their density.

Deep cleaning (to the value HF) of wastewater is provided with the applying of sorptive materials of vegetable matter, in particular the pools with the sawdust for example.

The technical and economic calculation of the cost of treatment process of oily wastewaters gave us an opportunity to find out that it is advantageous to use 5 layers (65 cm) of untreated sorptive materials of vegetable matter and 5 layers (65 cm) – treated ones at the temperature 200°C. Consequently 5 layers of untreated sawdust are filled up to 4 and 5 pools and 5 layers of treated one – to 6 and 7 pools (see fig.1).

After the passing of oily water with the volume 165,5 m³ per year through the untreated sawdust (4 and 5) the concentration of oil products in it decreases twice (fig. 2,a). The ability to soak up the sorbent fully is not lost (tab.4) therefore the replacement of sorbent in the pools can be done once per a year that decreases the necessary volumes of sorbent. The frequency of change of sorbent is defined at the base of control of concentration of oil products in wastewaters after the passing through the pools 4 and 5; 6 and 7. To ensure the uninterrupted process of treatment of polluted wastes we proposed to place the pools 4,6 and 5,7 in the parallel way (see fig. 1.)

If it is necessary to change the waste sorbent, for example, in pools 4 and 6, consequently the pools 5 and 7 will be able to work and ensure the necessary treatment.

Table 4 Efficiency of treatment by untreated and thermally treated sawdust after the repeat using

<table>
<thead>
<tr>
<th>Before treatment mg/l</th>
<th>After treatment, mg/l</th>
<th>Degree of treatment Y, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>untreated (20 °C)</td>
<td>treated (200 °C)</td>
</tr>
<tr>
<td>1,880</td>
<td>1,683</td>
<td>0,932</td>
</tr>
<tr>
<td></td>
<td>1,743</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td>1,872</td>
<td>1,312</td>
</tr>
</tbody>
</table>

Below in tab.5 there is the comparison analysis (according the cost) of five proposed flowsheets.

The flowsheet 4 is the optimum because the cost of treatment process is the smallest and amounts to 39 600 and 29 800 hryvnas for sawdust and sunflower peeling respectively. The quantity of sorbent layers used at this is 10 id est as it was said above is composed of 5 layers of untreated raw and 5 – treated at the temperature 200 °C.

The nomogram diagrams were built for comparison of five proposed flowsheets of treatment as for the cost of the process (see fig. 2) which reflect the changes of oil products concentrations in wastewaters of the volume 165,5 m³ (annual consumption of the airport) depending the put means (in coordinates: concentration-cost) at different temperature of processing of sorbent for all abovenamed technological treatment systems. The points on the graphics show the corresponding achieved meaning of concentration and expenses during passing of oily wastes through each layer of the sorbent with the height 13 m to the reaching of meaning HF of oil products in wastewaters 0,05 mg/l, which is indicated on the figures with the line of crimson color. The points of crossing of curves of concentration of oil products with this line on the scale of abscises correspond the cost of indicated technologies.

The search of optimum technology of cleaning of wastewaters on the given nomogram diagrams of reducing of concentration of oil products with corresponding expenses for different conditions of temperature processing of sorbent is the typical task of the dynamic programming which consider the process of consequent Choice of sorbent layers with different thermic treatment to minimize the general value and cost spent for the technological process. As the
calculations show the best variant for all presented flowsheets is when the sawdust processed thermally is filled up into all pools. But the process of thermal treatment is rather labor intensive and there is the flowsheet when the general expenses are somewhat bigger but the volume of thermally treated sawdust is half less. At this flowsheet the first pools are filled with the untreated sawdust and the other – with the treated one. This variant is shown with red color on Fig.2. It is also worth to note that increasing the expenses for thermal treatment relative to the expenses for untreated sawdust this variant of the technology will be the optimum.

<table>
<thead>
<tr>
<th>№ of technological VARIANT</th>
<th>Flowsheet</th>
<th>Expenses, hr.</th>
<th>$5(20^0С)$</th>
<th>$5(200^0С)$ layers</th>
<th>Including the expenses for thermal treatment of sawdust, %</th>
<th>Sunflower peeling</th>
<th>Expenses for treatment by non thermally treated sawdust, hr.</th>
<th>Including the expenses for thermal treatment of sawdust, %</th>
<th>Expenses for treatment by thermally treated sawdust, hr.</th>
<th>Including the expenses for thermal treatment of sawdust, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Without cost of sorbent utilization</td>
<td>43 100</td>
<td>30 800</td>
<td>54/52</td>
<td>52 200</td>
<td>0</td>
<td>40 300</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Without cost of sorbent *</td>
<td>58 700</td>
<td>43 200</td>
<td>40/37</td>
<td>84 150</td>
<td>0</td>
<td>50 500</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>All expenses</td>
<td>84 100</td>
<td>63 500</td>
<td>28/25</td>
<td>136 400</td>
<td>0</td>
<td>67 300</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Without cost of sorbent, with change of thermally treated sorbent, once/year</td>
<td>39 600</td>
<td>29 800</td>
<td>29/27</td>
<td>63 100</td>
<td>0</td>
<td>32 000</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>All expenses and change of thermally treated sorbent, once/year</td>
<td>58 600</td>
<td>45 000</td>
<td>20/18</td>
<td>102 300</td>
<td>0</td>
<td>44 600</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* At the most enterprises of woodworking industry the sawdust is the free material, only its transportation demands the expenses.

Therefore to reach the meanings HF for oil products (0,05 mg/l) the using of 10 layers of sorbent is the optimal: 5 layers of untreated raw and 5 layers of raw treated at the temperature 200 °C (point of crossing of the optimum curve indicated by red color and the line of alarm norm which is depicted with crimson color and placed parallely of the axis of abscisses).

The alternative to the using of 10 layers of the sorbent at the base of sawdust and sunflower peeling is the using of 21 layers of untreated vegetable wastes or 7 layers treated at the temperature 200 °C, to reach the meaning of GDK of oil products in wastewaters.

Today the question of the utilization and regeneration of waste sorptive materials is not fully studied. Such materials after the dehydration as a rule are gone out to the polygons of industrial wastes which is not grounded economically.

Regeneration of sorbents at the base of vegetable raw by chemical methods is not advantageous because demands the consumption of large quantity of reagents and also becomes the problem of the further wastes which appeared. Concerning this the thermal treatment of sorbents with residual content of oil products is interesting. The utilization of wasted sorbents was made by means of burning in the stationary boiler-room on the territory of the factory 410-ЦА., located at the distance not more than 2 km from the treatment facilities of the airport. Gas analyzer used for the control of the products of the burning did not fix the values over the norms. To prevent the pollution the atmosphere the using of thermic and catalytic processes and polymer components. But this aspect of the problem demands the further additional researches.

The proposed flowsheet can be taken as the basis for the development of the schemes of treatment of oily wastewaters of many enterprises of oil branch.

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