Research of the stressed state of saline rocks of Prykarpattia deposits under the influence of thermobaric conditions

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SUMMARY

The analysis of industrial data on casing string collapse was carried out at Oriv-Ulychniansky oil field and in the fields of the Dolyna region. It was found that the occurrence of salt-bearing rock intervals in the well section as well not taking into account the effect of rock pressure have the greatest negative impact on the integrity of the casing strings when designing casing strings in such rocks. Based on experimental studies with core material from wells in the Prykarpattia fields, the effect of pressure and temperature conditions on the fluidity of salts has been researched, which make up the section of Vorotyshchenska suite. It is found that at temperatures above 70°C the coefficient of lateral expansion of these deposits is equal to one. For such conditions, it is recommended to calculate the casing strings for external excess pressure, taking into account the rock pressure.

Introduction. Collapse of casing string occurs both during drilling and operation of oil and gas wells in most fields in Ukraine. This problem is especially essential for wells, in which sections creeping saline rocks occur. To develop measures for increasing the durability of casings usage, it is important to study the mechanism of manifestation of rocks creeping to determine the values of external pressures influencing the casing strings in the rocks.

Analysis of industrial data. In Oriv-Ulychniansk oil field of Boryslav oil area, there were eliminated 12 of the 40 drilled wells due to casing string collapse. And most of the cases a casing collapse happened during the operation of wells. Only in the 58-Ivaniki well a 324-mm casing was deformed at a depth of 2410 m while drilling, and after five years of operation the 168-mm casing at a depth of 2412 m was collapsed again. In most wells, casing string collapses were detected after long-term operation (12-15 years), although there are a number of wells where damage to the casing was detected after 3-7 years (99-Oriv, 58-Ivaniki) after their setting into operation.
The method of predicting casing deformation zones based on well curvature can be considered to be informative. Inclinometric measurements on a number of wells (17-Oriv, 21-Oriv, 99-Oriv, 158-Oriv, 17-Ulychno) showed that casing string collapse happened in the intervals of wellbore bends.
The study and analysis of the geological structure of the Oriv-Ulychniansk deposit do not reveal the regularities of casing collapse depending on the structure of the deposit, although wells with collapsed casing strings are located in two anomalous zones according to geodynamic characteristics.
The first of the zones is uncertainly mapped by aerospace survey in the form of a lineament, which diagonally intersects the thrust structures of the first and second floors, without being reflected in their structure according to drilling and seismic data (*Artym et al., 2019*). If the width of the zone is considered to be 1 km, then within the structure of the first layer there are 31 wells, in 9 (about 30 %) of which the casing strings are collapsed. Due to geophysical studies, it was found that the casing collapsed in the clay-saline deposits of the Vorotyshchensk floor (1520-2600 m), mostly in layers of pure salt (halite) or very saline clays, which are capable of plastic flow under certain thermobaric conditions.
Another abnormally tectonic stress zone is located in the main part of overlapping Boryslav-Pokutsk area. Here, between the front lines of the first and second layers, i.e. in the zone of the greatest geostatic tension, there are wells: 2 ÷ 17 Ulychno, 39, 96 - Ulychno. It should also be noted that in this case, the casing string collapse is not observed systematically in the wells, as well as in the placement of the wells themselves with collapsed casing in the area.
In these two zones, 12 wells were eliminated due to casing collapse while well operation. In addition, seven wells were closed for geological reasons and seven wells were abandoned for other technical reasons. It should be noted that in the anomalous areas production wells have operated up to today.
Table 1 contains a brief description of wells with collapsed casing strings at the Oriv-Ulychnyansk field.

***Table 1** Data on casing string collapse at Oriv-Ulychnyansk deposit*

Well number	Actual depth, m	Diameter of the column, mm / depth of the string descent, m		Depth of collapse, m / Deposits
		intermediate	production	
2-Ulychno	3253	193/2842	127/3116	2200/ vorotyshchensk
17-Ulychno	3477	193/2826	127/3243	528/ polianytsia
39-Ulychno	3395	193/2723	127/3388	1725/ vorotyshchensk
96-Ulychno	3363	193/2652	168/3282	2170/ vorotyshchensk
158-Oriv	3301	219/2785	146/3267	1927/ vorotyshchensk
21-Oriv	3288	193/2229	127/3185	2300/ vorotyshchensk
99-Oriv	3367	245/1301	146/3353	2496/ vorotyshchensk
17-Oriv	3405	193/2603	127/3392	2875/ polianytsia
95-Ulychno	2985	219/2485	146/2982	1320/ vorotyshchensk
175-Oriv	3605	245/2817	146/3605	2319/ vorotyshchensk
25-Oriv	3631	193/2750	127/3627	3567/ menilite
58-Ivanyky	3737	324/3522	168/3560	2412/ vorotyshchensk

The analysis of productive data on deposits in Dolyna region (*Shatskyi et al., 2019*) also shows that almost all cases of casing collapse occurred in the intervals of creeping rocks.
Using the theory of pattern recognition the multifactor analysis shows that the most significant impact on the collapse of casings in oil and gas fields of Prykarpattia is the presence of saline intervals in the section of wells and disregard for the action of rock pressure in the design of casings in such rocks (*Femiak et al., 2019*). In these intervals, under certain thermobaric conditions, rock pressure can be transmitted to the casing string. To study the process of pressure transfer from the saline rock to the casing, it is necessary to conduct experimental studies.

Method. In order to conduct experiments, a special laboratory unit has been made, which enables to study the stress state and creeping point of rocks exposing formation pressure and formation temperature (Figure 1).

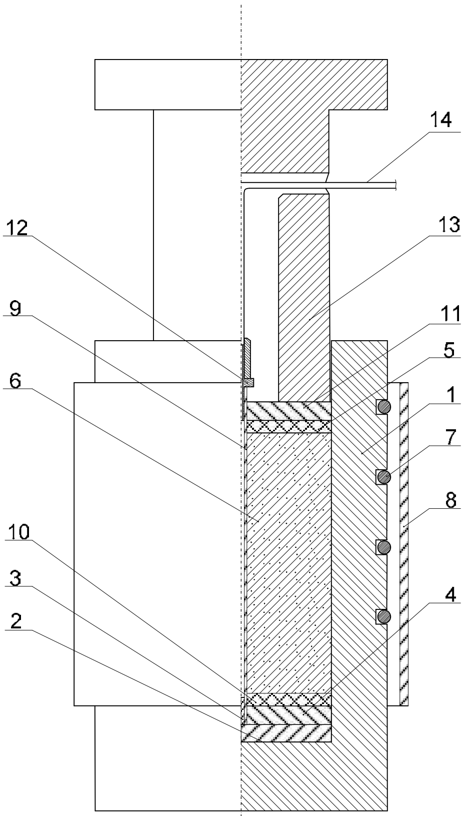

Figure 1 Scheme of a high-pressure chamber for studying stress state of rocks: 1 – thick-walled cylinder; 2 – cylinder bottom; 3 – plug; 4,11 – steel washers; 5,10 – rubber gaskets; 6 – sample of the rock; 7 – heating element; 8 – protecting cover; 9 - steel pipe; 12 – adapter; 13 – plunger; 14 – inlet pipe

For this purpose, the core material of vorotyshchensk floor was used with a high halite content (65÷99 %). The sizes of the samples were chosen according to existing methods, i.e.

$$D \geq 5 \cdot d \;\; ; \;\; \frac{h}{\sqrt{S}} \geq 0{,}7 \, , \qquad (1)$$

where D - outer diameter of the sample, m; d - diameter of the simulated well, m; h - height of the sample, m; S - cross-sectional area of the rock sample, m^2.
The outer diameter of the sample was determined by the core diameter and was 80 mm, so the diameter of the simulated well was 16 mm and the height of the sample was 100 mm.
Rock sample 6 was placed in a high-pressure chamber, which is a thick-walled cylinder with a bottom and heating element 7. The heating element is externally closed by protecting cover 8, and compaction of the rock sample was carried out using steel washers 4, 11 and rubber gaskets 5, 10. A hole with a diameter of 16 mm was drilled inside the sample, into which steel pipe 9 of the same

diameter with a wall thickness of 2.2 mm was inserted. The pipe was used as a sensor for measuring the external pressure transmitted to it by the rock sample. Plug 3 was screwed into the lower end of the pipe and adapter 12 was screwed into the upper end. The ends of the pipe were welded to seal the joints. The pipe was filled with insulating oil and pressure was created with a hydraulic press through inlet pipe 14 and adapter 12. Thus, the external radial pressure transmitted to the pipe by the rock sample caused a change in pressure inside the pipe, which was registered by a manometer.
The axial compressive load was created by means of plunger 13 and a hydraulic jack placed above and below the high-pressure chamber. The temperature in the chamber was regulated by changing the voltage applied to the heating element.
Due to the fact that the direct measurement of both the radial pressure transmitted to the pipe and the temperature inside the chamber was difficult during the experiments, the unit was calibrated by pressure and temperature. This made it possible to determine the temperature inside the chamber by the value of the voltage supplied to the heating element, and the value of the radial pressure transmitted to the pipe by the value of the pressure inside the pipe.
The following method was used while studying samples of saline rocks. The rock sample was placed in a high-pressure chamber. The pipe was filled with insulating oil and pressure of 3.0 MPa was created with the help of a press. Before carrying out experimental studies, the rock samples were dried in an oven at temperature of 50°C for 48 hours.
Using a hydraulic press, an axial load was created in the high-pressure chamber, which simulated the rock pressure for given depths. The axial load on the rock sample was increased smoothly to a predetermined value, which was monitored by changing the value of the internal pressure. The rock sample was kept in a stressed state for at least 72 hours or until the rock pressure was completely transferred to the pipe.

Results. The results of experimental studies were processed using the methods of mathematical statistics. The deviation of the results was within 5 %. Based on the results of experimental studies, the dependence of the lateral expansion coefficient of salt-bearing rocks K on the temperature t at different values of normal stresses σ_z was obtained. Figure 2 shows the dependence of K = f (t) at σ_z = 70MPa, from which it can be seen that temperature significantly affects salts creeping.

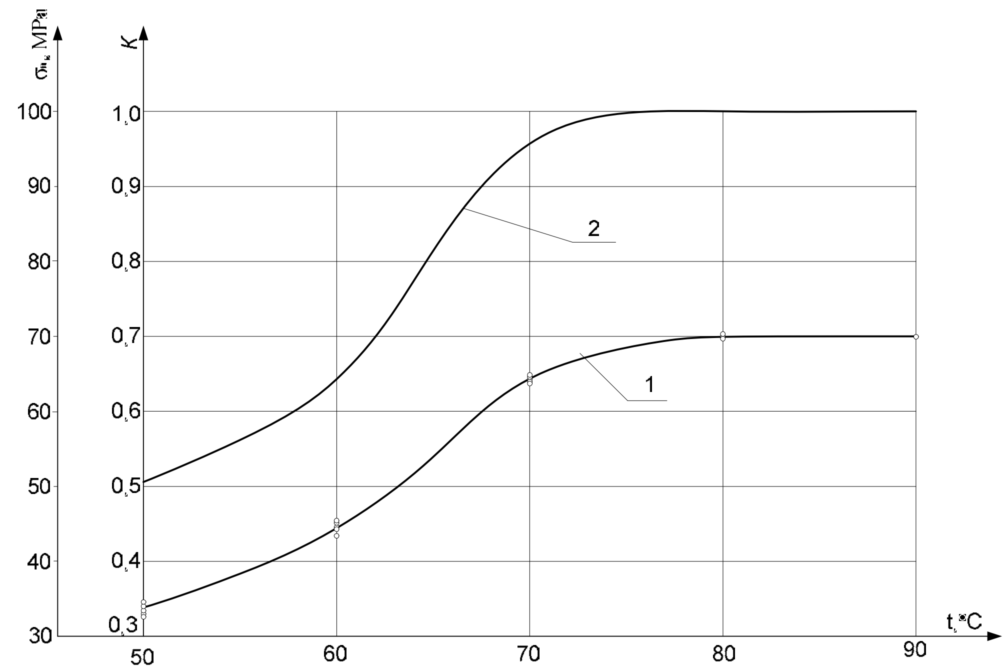

Figure 2 *Dependence of the lateral expansion coefficient of salt-bearing rocks (halite) on temperature (*σ_z = 70 MPa): 1 – radial stresses (σ_r); 2 – *lateral expansion coefficient* (K = σ_r / σ_z)

At temperatures above 70°C, the value of the lateral external pressure on the pipe approaches the vertical component of the pressure. At a temperature of 80°C and above $\sigma_r = \sigma_z$, i.e. the coefficient of lateral expansion of saline rocks (halite) is equal to one. Therefore, in the intervals of saline rocks occurrence at temperatures above 70°C, the rock pressure is completely transferred to the casing strings.

The temperature of the near-wellbore rock massif depends on its natural temperature field and the nature of technological operations performed during drilling and operation of wells. So, in the process of fluid movement to the wellhead through the tubing as a result of heat exchange with rocks that cover the casing string, its temperature decreases. At the same time, the temperature of the casing and rocks around the well rises and becomes higher than the natural temperature of the rock massif. After some time of well operation, a constant flow of thermal energy is practically set in. Theoretical calculations and experimental studies (*Cheremenskij, 1960*) have shown that the diameter value of the violation zone of the thermal regime can reach 10–20 m and more. One of the reasons for the increase in the natural temperature of rocks is also the injection of heat carriers into the formation in injection wells.

Conclusions. The analysis of industrial data on the Oriv-Ulychniansk oil field of Boryslav oil field area and the fields of Dolyna region did not reveal the regularities of casing collapse, depending on their geological structure. However, almost all cases of casing string collapse occurred in the intervals of occurrence of salt-bearing rocks.

To study the stressed state of rocks under the influence of rock pressure and formation temperature, a laboratory unit was made. It is found that when the temperature rises above *70℃*, the coefficient of lateral expansion of saline rocks is equal to one.

Calculation of casing strings for external overpressure in the intervals of occurrence of salt-bearing rocks in Prykarpattia fields must be carried out taking into account the rock pressure:

- for wells for various purposes, if natural temperature of the rocks exceeds *70℃*;
- for injection and production wells, in which technological operations are planned to be carried out that may cause an increase in the temperature of the near-wellbore rock massif of more than *70℃* (for example, when heating fluids are pumped into the formation in injection wells, when transporting a fluid with a high temperature in production wells).

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