Oil and gas well drilling technology based on the system approaches and the results of application

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Abstract. The article analyzes the reason and factors of declining in key indicators of quality and efficiency of well construction and operation, which have led to a long-term stagnation in drilling technology. To handle the urgent issues, a systematic approach to implement the complex of hydro-mechanical hardening of an open-hole well by the synchronous and coordinated action of hydraulic monitoring strings of drilling fluids is proposed. The indicators of quality and efficiency of the complex compared to the traditional ones, which exceed the former by two or more times, are provided.

1. Introduction

The steady tendency for the increasing complexity of the geological and technical conditions needed to construct and operate the oil and gas wells of both natural and man-made origins is increasingly negatively affecting their quality and efficiency [1, 2]. The current situation is due to two circumstances.

The first one is a logical decrease in the efficiency of traditional drilling technologies and well completion in abnormal and changing geological, technical and thermodynamic conditions. Based on the principles of maintaining hydraulic equilibrium in the "well – rock mass" system as a factor in preventing gas and oil occurrences, emissions and stabilizing the production conditions of technological operations, these approaches cause the non-stationary technical state of the borehole and the uncertainty of the hydraulic behaviour of wells, characteristic features of those are close to chaotic (for the processes of hydro-mechanical and physical-chemical interaction of the rock mass, process fluids and reservoir fluids).

The second circumstance is the lack of effective methods to control and manage technological processes of drilling and operation of wells (it refers to the regulation of mechanisms of hydro-mechanical impact on permeable rocks of the near-well and remote zones: absorbing rocks, gas-oil-water-saturated layers and unstable rocks).
The negative impacts of these circumstances are logical decreases in key indicators of drilling and operation of wells: the deterioration of filtration characteristics of the productive formations, the violation of the sealing capacity of the support, the consolidation of fluid-saturated layers of the effective thickness into a single filter, the differentiation of the current reservoir pressure by the section and area of the developed oil and gas deposits. In the final analysis, the result is a decrease in the integral indicator of the efficiency of oil and gas deposits development – the oil recovery coefficient (ORC), as well as an increase in one of the key negative technological indicators of field development – the water-cut of the extracted products [3-7].

2. Methods and materials
Long-standing monitoring has shown that the use of traditional and newly developed technologies does not lead to an effective solution to key technological problems. It was the reason for the long stagnation in the field of construction and well operation. However, among the majority of specialists, there is a strong opinion that the existing technological problems in drilling (the prevention of complications: absorption, gas and oil occurrences, rock instability, preservation of natural reservoir properties of the effective formations, increasing the sealing capacity of the borehole annulus of the support, etc.) can be successfully solved by the changing of the rheological properties and parameters of process fluids (drilling, grouting and special solutions), the optimizing of drilling modes, support setting and completion of wells, etc.

However, the results of field research and experience show that this opinion does not have sufficient scientific justification, is not confirmed by practice, and is very controversial in many circumstances [1]. This is primarily due to the unsteadiness of hydraulic drilling conditions, which are not subject to control and regulation of the processes of hydro-mechanical and physical-chemical interaction of drilling fluids and the opening drilling of a rock mass by an irreversible violation of the initial properties of drilling and grouting solutions in the well.

Field studies of the recent years show that the cause of most complications in the well is an active hydraulic connection of drilling fluids and fluid-saturated layers in the array of rocks opened by drilling with different filtration and strength characteristics. The final result of these non-stationary, uncontrolled thermodynamic processes is a violation of technology, a decrease in the quality and efficiency of drilling operations, and well operation.

3. Results and discussion
To handle these complex field issues (the stabilization of the hydraulic state and behaviour of wells, the preservation of the natural reservoir properties of productive layers and their isolation from the fluid-filled reservoirs of the productive thickness, the increase of sealing capacity of the borehole annulus) the complex of technologies has been designed and developed (table 1) [1], which in turn is closely connected with the key problems of the increasing efficiency of development of oil and gas deposits, the maintenance of high rates of hydrocarbon production, the prolongation of waterless operation of wells, the increase of ORC [2, 9-12].

The methodological basis of the proposed technology is the simultaneous strengthening of the borehole with the drilling process by water jets directed at the walls of well [8]. The near-wellbore forming waterproofing screen occurs when the synchronous and coordinated occurrence of hydrodynamic processes and transforming the kinetic energy of the water jet in the quantum of the pressure pulse at which the force of the dynamic impact of the jet is 0.15–0.40 t, the contact time with the rock is 0.012–0.017 seconds, the temperature of the processes is 500-800 °C (approximately [8]). Formed in these thermodynamic conditions, the near-wellbore waterproofing screen is characterized by the parameters: the thickness of the adhesive layer on the borehole wall is 3-5 mm; the depth of the zone of clogging in the matrix permeable rocks – 10-30 mm; hydromechanical strength of the borehole under the action of repression – 0.018–0.025 MPa/m (gradient of rock pressure); the sealing capacity of the borehole during the depression – 0.010–0.015 MPa/m [1, 8].
Table 1. The complex of advanced technology for drilling and completion of wells

| Methods of the technological complex | Purpose of complex elements | Final results of the complex implementation |
|--------------------------------------|-----------------------------|---------------------------------------------|
| 1. The technology of water jetting of the borehole in the drilling process and selective effects | Restoration of waterproofing of the exposed absorbing and oil-and-gas-saturated reservoirs from the wellbore | Operational evaluation of technical condition indicators of the wellbore |
| 2. Method of the rapid assessment of the technical condition of the borehole (the sealing capacity and the strength of the walls) | Monitoring the sealing capacity and strength of the borehole, assessment of filtration characteristics of fluid-saturated reservoirs | Prevention of complications and optimization of hydraulic drilling and completion processes |
| 3. Method of isolation of absorbing layers with an intensity of more than 50 m³/hour. | Restoring the sealing capacity and strength of the borehole in the conditions of abnormally low formation pressure (ALFP) | Complete isolation of high-intensity absorbing layers (50 m³/h or more) |
| 4. The technique of selection and implementation of the mechanism for reducing reservoir permeability, calculation of optimal parameters of the isolation process | Operational control and regulation of permeable rock isolation mechanisms and strengthening of unstable rocks | Non-linear improvement of quality, technical, economic, environmental indicators and safety of drilling operations |

Features of the proposed technology are the following:
- creating a fluid-proof clogging screen when the sections with the absorbing and oil-water-gas comprising layers and the rocks which are prone to hydraulic fracturing are opened;
- preventing scree and failure of unstable rocks due to the formation of a highly-structured clogging layer;
- requiring minimal energy consumption to pump the solution with simultaneous creating a highly-structured wall layer and a layer in the clogging zone (figure) due to its unique rheological properties;
- applying is recommended with clay-based drilling fluids, including cement.

The analysis of cavernograms and the comparison of actual cavernosity ratio during drilling wells with the use of hydro-mechanical hardening technology allowed ensuring significant stability of the borehole within the range of the verye horizon, which is prone to scree and failure.

The transition to the system level of development of traditional technologies is confirmed by the results of non-linear improvement of technological, technical, economical, environmental indicators, as well as the safety of drilling operations.

The integral indicators for reducing the time of the well construction were 20-25 %, increasing the current flow rate by 1.6-3.0 times and decreasing the water-cut of extracted products by 2.6 times. A more detailed assessment of the technological indicators of opening the productive layer using hydro-mechanical strengthening of the borehole of well is presented in Table 2, in the period from 2002 to 2004 in JSC "Tatneft" [8].
Figure 1. Distribution of the drilling fluid flow rate in the well and the near-wellbore zone of drilled reservoir rocks [8]

Table 2. The assessment of qualitative and technological indicators of the well completion through a system technology complex

| Implementation volume, wellbore | The thickness of the layer (perforated), m | Average operating indicators | The dynamic pressure gradient between w/s and o/s layers, MPa/m | Specific-productivity index, m³/(day×MPa×m) |
|---------------------------------|------------------------------------------|-----------------------------|-------------------------------------------------------------|------------------------------------------|
| Total: 56 wells                 | 1.0–2.0                                   | 8.49                        | 37.7                                                        | 3.7                                      | 5.4                                      | 1.79                                      |
| Total: 70 wells                 | 2.1–4.0                                   | 9.6                         | 30                                                          | 4.3                                      | 5.6                                      | 1.13                                      |
| Total: 41 wells                 | more than 4.0                             | 15.3                        | 35.4                                                        | 2.7                                      | 4.2                                      | 0.68                                      |
| Average values for test wells (the sample of wells drilled utilizing the complex technology) | | | | | | |
| Indicators of base wells        | 11.1                                      | 34.4                        | 3.6                                                         | 5.07                                     | 1.20                                     |
| The ratio of indicators of test and base wells | | | | | | |
| Comment: w/s, o/s – water-saturated and oil-saturated layers, respectively. | | | | | | |
4. Conclusion
The comparative analysis of technical and economical indicators of the drilled interval in the well with the same interval previously drilled nearby wells on the area demonstrated the high efficiency of the applied technology. In particular, the opening of the verey horizon at the well without the hydro-mechanical strengthening of the borehole, which further led to the destabilization of the borehole, specifically required the installation of a hardening cement bridging in this interval. When drilling through this technology, these problems were avoided and the installation of a cement bridging in this interval was excluded, respectively, which significantly reduced the time for construction of the well.

The analytical assessment presented in the article allows concluding that the transition to the system development and the improvement of technologies of drilling and operating oil and gas wells is one of perspective scientific and technical directions of non-linear improving the quality, efficiency, environmental protection and production safety in the drilling and operation of wells and increasing current oil production rate and reduce water-cut of the extracted product.

When using the technology, the following technical and economical indicators were achieved: the technical drilling speed was increased by 8.65%; the commercial drilling speed was increased by 6.5%; the cavernosity ratio was reduced by an average of 6.2%. The application of technology made it possible to exclude the installation of a cement bridging in the interval of the verey horizon.

The conclusions about the effectiveness of the proposed technology are stated to be preliminary and require the developed technology to be undergone further field tests. The application of technology has allowed to carry out high-quality wiring of the borehole under the production string and to increase the commercial speed of construction.

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