Results of system drilling techniques and completion of oil and gas wells

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Abstract. The article presents results of the improved technology for drilling and completion of oil and gas wells (Multi-technology Complex). The results are based on synchronization and consistency of thermodynamic processes of well bore strengthening and implementing system approaches and solutions. The authors discuss brief analytical generalizations on the quality and efficiency of well lining, factors that violate the well lining technology, and related problems. In addition, disadvantages of traditional technologies and the reason for their low efficiency in the construction of wells are mentioned. The authors give analytical generalizations of the results of well construction with the use of the Multi-technology Complex in various mining and engineering conditions of Russian fields. The method’s advantages over traditional methods are noted. There are no occurrences of various complications in a well construction: fountains, emissions, gas-oil-water manifestations, absorption, instability and hydraulic fracturing of rocks. Furthermore, the complex allows improve well and filter structures reducing the metal intensity of the structure and the time frame.

1. Introduction

It is known that final technological indicators of development of oil fields depend on the geological structure of deposits, development technologies [1–6] as well as on the efficiency of drilling and well completion.

An analytical review of the state of well construction technologies at deposits in Russia and abroad revealed a number of patterns that have a prevailing negative effect on quality, efficiency and safety in the drilling and operation of mining equipment. It needs to establish system communications and intrasystem effects. Their implementation leads to a non-linear (multiple) increase in the quality and efficiency of drilling and completion of wells [7–17].

Field experience shows that there are currently stable trends of stagnation in well construction and operation. The traditional technology of drilling wells with its modifications does not solve key technological problems. The reason is the inadequacy of technological developments in geological, technical and thermodynamic conditions for drilling and completion of oil and gas wells [9]. The factor
of this systemic contradiction in the traditional technology of drilling is the hydraulic connection of the thermodynamic system “well-rock mass” in well construction. Non-stationary vibration wave processes during drilling are one of the factors. They lead to hydrodynamic and physico-chemical interactions of process fluids and rocks. The result of this interaction are various kinds of complications, for example, absorption, gas and oil see-through, fracturing, emissions, etc. In turn, they violate the technology of drilling and reduce their quality and efficiency.

2. Materials and methods
To solve key technological problems of drilling, for example, stabilization of technical state of the open hole, hydraulic drilling conditions, preservation of natural reservoir properties of productive layers, the formation of long-term tight support and filter wells, BashNIPIneft and UNI institutes (1978-1980) developed the Hydromechanical Multi-Technology Complex for hardening of the wellbore [9, 10]. The methodological basis is synchronization of drilling wells and hydromechanical strengthening of a well bore, which is directed to a well wall by a jetting of drilling mud [7, 8]. The formation of a near well bore waterproofing screen occurs under the kinetic energy of jetting, which is transformed into a field of quantum high-amplitude and low-frequency pressure pulses. The thermodynamic process of waterproofing has the following indicators of technological impact: the force of the dynamic impact of the jet is 0.15-0.40 t., The time of contact with the rock is 0.012–0.017 s. The temperature of the illuvial medium is 500–600 °C (approximately).

The near well bore waterproofing screen has the following technical indicators: a thickness of adhesive layer on well walls – 2-3 mm; a colmation zone depth in the matrix of permeable rocks – 10-30 mm; the gradient of trunk hydromechanical strength during repressions is 0.018-0.025 MPa / m, during depressions – 0.010-0.012 MPa / m.

The achievement of the noted indicators of the technical state of the well bore (Table 1) became the scientific and technical basis for the transition from the disordered traditional drilling technology to a systematic level of development [9, 10]. As a result, non-linear improvement of quality, technical-economic and environmental indicators, the reduction of emergency safety of drilling operations are realized due to intrasystem effects: the organization and management of technological mechanisms of influence on rock formations [10, 11].

3. Results and discussions
Field tests and results of the commercial introduction of the Multi-Technology Complex showed that the hydromechanical strengthening of a well bore during a well drilling (Table 1) blocks the hydraulic connection between the barrel and process fluids at various oil and gas fields. In turn, it excludes thermodynamic interactions in the geological and technical system and complications that violate the technology of drilling operations. At the same time, the Multi-Technology Complex optimizes hydraulic conditions for the production of drilling and completion operations, reduces environmental and emergency risks (ring flows, griffins, emissions and fountains) with increasing hydraulic repressions up to a rock pressure gradient (0.018-0.023 MPa) and a reduction of depressions to 5.0 MPa (elements of self-organization of the technical system due to the manifestation of intrasystem effects).

Field experience showed that the technology of hydro-mechanical hardening prevents complications of lining tightness [10, 11] in various geological and technical conditions of well drilling and negative consequences. At the same time, technical indicators of the lining (a tightness and a hydro-mechanical strength) increase multiply (Table 2).

Results of the widespread introduction of hydromechanical hardening of the wellbore showed that they do not have any disadvantages of traditional technologies [10–17]. For example, in 2014-2015 the wells at the Kuleshovskii field had been drilled in the range of 1900-2370 m under a 245 mm technical column. At that time 5-7 areas of complications were opened: a mud absorption, gas manifestations, interlayer overflows, and tool sticking (Table 2).

The expense needed to combat complications of traditional technologies is higher than for system technologies. It happens because there are no all the noted complications in the hydromechanical
strengthening of the wellbore (Table 2). In some cases, for example absorption, their temporary and weak signs are noted. At the same time, the process of drilling occurs continuously without any technological disruptions and stops.

Well completion is a construction phase, which determines final quality indicators, an effectiveness of environmental protection and safety of technical facilities. In contrast to the upper drilling interval for a technical column the well completion technology has more complex geological-technical, thermodynamic drilling conditions, the initial opening of the productive strata, and the well casing by a capital string [9]. The negative impact of the latter on the technology is associated with the unsteady thermodynamic state and behavior of the deposits being developed: a differentiation of a current reservoir pressure over a section and area, interlayer flows in most production wells, uncontrolled change in the pressure gradient between productive and water-saturated formations, a combination of unsaturated formations and an operational object.

The traditional technology of drilling in these conditions cannot solve key problems of well construction [9] such as the formation of long-term hermetically sealed lining, a protection of natural properties of productive formations, a blocking of formation water inflow to the well filter. The Complex of Multi-Technology for hardening of the wellbore solves all these problems. The integral indicators are presented in Table 3 and Table 4.

The analytical generalization of the presented materials allows us assess the technological capabilities of system development and draw the appropriate conclusions about the further system development of drilling technologies.

**Table 1.** Results of the field evaluation of filtration and strength characteristics of the near wellbore zone of productive sediments after a water jetting

| No. well, area | Test interval, m | Test data | Filtration and strength qualities of a productive interval |
|---------------|-----------------|-----------|----------------------------------------------------------|
|               |                 | Proof pressure, MPa | Density of drill mud, kg/m³ | Ratio of full infectivity, m³/s MPa 10⁻² | Pressure gradient of a full-hole testing of strength, MPa/m 10⁻¹ |
|               |                 | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
|               |                 | treatment | treatment | treatment | treatment | target | reduction, unit | treatment | treatment | reliability | improving factor, unit | Fracturing | grading |
| 3184, N-Kh   | 1213.3-1263.0   | 1180   | 10.0 | 15.0 | 0.70 | 0.21 | 3.3 | 0.20 | 0.24 | 1.20 |
| 5603, N-Kh   | 1224.8-1274.6   | 1300   | 7.0 | 15.0 | 0.50 | 0.25 | 2.0 | 0.19 | 0.25 | 1.31 |
| 5604, N-Kh   | 1221.4-1274.0   | 1360   | 7.0 | 15.0 | 1.10 | 0.51 | 2.1 | 0.19 | 0.26 | 1.37 |
| 5909, N-Kh   | 1206.6-1253.2   | 1240   | 8.0 | 15.0 | 0.90 | 0.48 | 1.9 | 0.19 | 0.25 | 1.31 | 0.209- |
| 8027, N-B    | 1307.3-1353.3   | 1340   | 6.0 | 15.0 | 1.00 | 0.40 | 2.5 | 0.17 | 0.25 | 1.47 | 0.216 |
| 8079, N-B    | 1327.7-1371.5   | 1340   | 6.0 | 10.0 | 0.76 | 0.33 | 2.3 | 0.18 | 0.21 | 1.17 |
| 6525, V      | 1321.2-1362.1   | 1100   | 7.0 | 10.0 | 1.10 | 0.22 | 5.0 | 0.16 | 0.19 | 1.19 |
| 7459, V      | 1247.2-1291.0   | 1100   | 6.5 | 11.0 | 1.50 | 0.35 | 4.3 | 0.16 | 0.19 | 1.19 |

Notes: Indicators in the column “Before the treatment” refer to the opening of the interval with traditional technology, the column “After the treatment” – to the subsequent water jetting of rock formations of the test interval.

N-Kh – Novo-Khazinskaia area of the Arlanskii deposit, N-B – Nikolo-Berezovskaya area of the Arlanskii deposit; V – Viatskaia area of the Arlanskii deposit.
Table 2. Comparative indicators of well drilling with traditional and system technologies

| Complications | No. well and Affiliation | Serial: 78, 79, 87, 90, 219 | Test: 83, 84, 85, 86 |
|---------------|--------------------------|-----------------------------|----------------------|
| Number of intervals, unit | | 5-7 | |
| Absorption rate, m³/h | | 5-60 | |
| Gas and water show intensity, m³/h | 28-90(25-40) | Weak features or no features | |
| Absorbed borehold mud volume, m³/well | 170-520 | (short-term leaks) | |
| Grouting mortar consumption (GMC) m³/well | 125-200 | 40 | |
| Total time of insulation operations, day/well | 5-12 | 0.5-1.0 | |
| Quantity of insulation operations, item/well | 3-11 | not produced | |
| Expenses, million rubles/well | 10.4-24.5 | 1.5-1.7 | |
| Insulation success rate, % | 25-33 | 100 | |

Qualitative indicators of drilling operations
- Destruction of drilling and grouting mortars, interstitial flows intensive water seepage, cavernousness 1.3–1.5
- Cavernousness <1.3

Notes: Stratigraphic horizons are Serpukhovskii, Okskii, Turneiskii, Famenskii. The type of complications is absorptions, gas and water manifestations, interfacial overflows, stickings. The test interval is 1900–2370 m (drilling under a 245 mm technical column). Tool stick are 1–2 cases per a serial well. Interfacial overflows and water showings are in all drilled wells.

During drilling wells in the installation interval of technical columns (up to the roof of productive sediments), the hydromechanical strengthening of the well bore ensures the implementation of the following technological effects, quality, technical and economic indicators of well construction (Tables 1-3):
- an optimization of hydraulic drilling conditions, casing cementing and prevention of complications;
- a preservation of original properties of cement slurries-stone;
- a protection against corrosive damage to casing and cement stone;
- an increase of tightness and lining service time;
- a multiple reduction of costs and time spent in the installation of technical columns.

Similar indicators were obtained during the completion of wells (Table 4). However, there is a difference: a non-linear increase in quality and efficiency occurs during the initial opening of the productive formation by drilling as well as the long-term operation of wells [9, 13]. It means:
- an optimization of hydraulic conditions of the productive strata initial opening, ensuring the continuity of the drilling process without complications and the protection of productive strata from contaminations;
- a stabilization of thermodynamic processes of cementing the capital string and forming a cement ring;
- a selective isolation of the productive strata from outsiders in the interval of the productive stratum;
- a prevention of possible emergencies (gas and oil manifestations, absorption, emissions and fountains) and well irrigation;
- a protection of casing and cement stone from corrosion damage.
Table 3. Indicators of the opening of productive deposits with the processing of the well bore by a water jetting of clay solutions in the Arlanskii deposit

| Parameters | No. well 715 | 814 | 705 | 861 | 779 |
|------------|--------------|-----|-----|-----|-----|
| Notions    | 16.5 | 17.5 | 16.5 | 16.0 | 16.0 |
| Thickness of water barriers, m | 7.5 | 10.0 | 4.0 | 10.4 | 5.2 |
| Pressure gradient between layers (oil-saturated), MPa/m | 0.32 | 0.24 | 0.6 | 0.58 | 0.36 |
| Drilling mud density, kg/m³ | 1520 | 1600 | 1440 | 1450 | 1450 |
| Hydrostatic bottom-hole pressure, MPa | 1.8 | 3.1 | 0.9 | 1.6 | 1.6 |
| Drilling mud density, kg/m³ | 1360 | 1400 | 1320 | 1230 | 1200 |
| Hydrostatic bottom-hole pressure, MPa | -0.9 | 0.5 | -0.5 | -1.2 | -1.5 |
| Real flushing fluid density, % | 10.5 | 12.5 | 8.3 | 15.2 | 17.2 |

Notes: Testing of the water jetting of the productive interval was carried out on the section with an increased current reservoir pressure (Pressure anomaly coefficient 1.13-1.24).

Table 4. Technical and economic indicators of well design improvement

| Indicators | Severo-Komsomolskoe | Karachaganskoe |
|------------|----------------------|----------------|
| Growth performance of bits, % | 22-34 | 25 |
| Reduction of complications, % | 75-80 | 90 |
| Volume reduction of drill cuttings, % | 21 | 27 |
| Reduced metal structure, % | 18-20 | 18 |
| Reduction of well construction time, month | 2-3 | 3-5 |

As a result, the integral indicators of drilling operations increased by 20–25%, the current production rate increased by 1.6–3.0 times, the water content of the extracted products decreased by 2.0–2.6 times. The main indicators of quality, efficiency, environmental and industrial safety of the construction and operation of wells are presented in detail in the table.

The hydromechanical strengthening of the well bore leads to a nonlinear increase in basic well construction indicators, creates optimal thermodynamic conditions for improving the design of deep wells and a filter (Table 4), makes it possible to complete wells with an open bottom [9]. Ultimately, all non-linear improvements in the quality, efficiency, environmental and technical safety of oil and gas well construction lead to a significant reduction in expenses and time.

4. Conclusion

The results of the Multi-Technology Complex for hardening of the wellbore allows make a conclusion about the prospects for a system development of improving technologies for the construction and operation of oil and gas wells in various geological and technical conditions of hydrocarbon deposits. In comparison with traditional technologies, the Multi-Technology Complex meets key construction requirements, well operations and a development of oil and gas fields. Other words, the maximum technical and economic effect will be achieved with minimum material and financial expenses.

Based on the final indicators of quality, technical and economic efficiency, environmental protection and technical safety of the construction and operation of wells, the Multi-Technology Complex is a highly profitable, competitive and patented (7 active patents) development, which has no analogues in domestic and foreign practice.
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