WELL COMPLETION OPERATIONS WITH THE USE OF THE MULTI-TECHNOLOGY COMPLEX OF THE WELLBORE HYDRODYNAMICAL HARDENING

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Abstract

The urgency of the issue under consideration is stipulated by the fact that the technologies of casing string cementing traditionally applied while developing oil fields do not always provide the necessary long-term impermeability of casing support. Therefore, this article is aimed at solving the mentioned key technological problem of well drilling. The Multi-technology Complex of the Wellbore

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Hydromechanical Hardening (KMGUS) is proposed as a basic research method. The methodological basis for the research is the synchronization (simultaneity) of well drilling and the hydromechanical hardening of wellbores by jetting out a drilling fluid at wellbore walls. The following particular problems have been solved: maintaining stability of the uncased wellbore and hydraulic drilling conditions, ensuring maintaining of natural reservoir properties of productive formations, forming a long-term tightness of casing support and wellbore screen. The proposed method has been partially introduced into production. The results of industrial pilot tests have proved the high efficiency of KMGUS, which prevents the appearance of most problems when constructing oil and gas wells: absorption; gas, oil, and water shows, hydraulic fractures and instability of the exposed rock formations, kicks and blowouts. In addition, during the well operation, the complex provides the prevention of annular fluid shows and cross flows. As a result, the production rates for wells drilled with use of KMGUS are 2 and more times higher compared with traditional well construction technologies, water cut is lower by more than 2 times, and as a positive effect is a non-linear increase in the oil recovery factor. The article can be useful for specialists in the field of construction of oil and gas wells, scientists and graduate students studying the casing strings cementing problems.

**Keywords:** Oil and gas wells, control and management method, technological processes, production string cementing, wellbore hydromechanical hardening, synchronization of drilling processes

I. Introduction

At present, there is a steady trend of increasing complexity of geological and technical conditions for construction and operation of oil and gas wells. Complicating conditions of natural and man-made nature negatively affect the quality and efficiency of well casing. This situation is due to two main circumstances.

The first circumstance is associated with a regular decrease in the efficiency of traditional well construction technologies in continuously changing and anomalous natural and technical conditions with non-stationary thermodynamics. Technologies, based on the principles of maintaining hydraulic equilibrium in the "well – rock formation" systems, are aimed at preventing: kicks; gas, oil, and water shows; stabilizing the conditions of technological processes. Unsystematic approaches and solutions in the conditions of unsteady well hydraulic behaviour, which is close to chaotic processes of physicochemical and hydromechanical interaction of formation fluids, process fluids and rock formations, lead to failures of wellbore integrity.

The second circumstance – to date, there are no effective management and control methods for technological processes of construction and operation of wells. The absence of methods regulating the mechanisms of hydromechanical impact is also relevant to near-wellbore and remote areas of permeable gas-oil-saturated strata, and absorbing and unstable intervals of exposed rocks.

Negative consequences of the above mentioned circumstances result in expected decrease in the key indicators of construction and operation of wells: well integrity failure, deterioration of productive strata filtration characteristics, integration of fluid-
saturated layers of productive strata into a single filter, annular fluid shows, water flooding of the extracted production, drilling mud springs, etc. Ultimately, all this factors stipulate a decrease in the integral indicator of the efficiency of oil reservoir development – oil recovery factor (ORF), and the increase of water cut in the extracted products.

As many years of experience show, the use of traditional and newly developed technologies does not result in an effective solution of most technological problems. This caused a long-term stagnation in this sphere. Nevertheless, the majority of specialists on the matter at hand believe that the current technological problems in drilling (absorption; showing of gas, oil and water, unstable rock formations, deterioration of natural reservoir properties of productive strata, well integrity failure) can be successfully solved by changing the rheological properties and parameters of process fluids (drilling fluids, cement slurries, and other special solutions by regulating the relevant parameters of pressure and circulation, etc.).

However, the results of field research and experience show that such beliefs do not have sufficient scientific justification, and are not practically supported, being highly controversial in many respects. That is why solving the problem of wellbore hardening by introducing new technologies is important and relevant.

II. Analysis of Well Cementing Quality

Analytical assessment of the current level of quality and efficiency of well cementing at the developed oil and gas fields shows that the traditionally applied casing string cementing technologies do not provide the functionally sufficient long-term impermeability for casing support. The main types of defects are associated with isolation of formations while sealing the annular space. There are some other defects of cementing: failure of a cement slurry to reach to the designed height (25-40%), non-uniform density of a cement slurry/hardened cement slurry in the annular space (85-95%), discontinuity in cement sheath (12-20%), breakthrough of rock formation fluids to the wellbore screen while developing wells, cross flows (8-21%) (overall indicators). Of the above defects, only the presence of non-uniform density zones in hardened cement slurry of the annular spaces is an indicator of casing unreliability (Table. 1). And this is one of the key problems in the construction and operation of wells.

Table 1: The results of cementing quality assessment for the production strings at the fields of Western Siberia (SDGRDFD data)

| Statigraphic Formations     | Typical Intervals of Cement Height, m | Initial Average, according to DGRDFD | Spread Slurry Density, g/cm³ | Cement Slurry Density, g/cm³ | Sealing Interval, m |
|-----------------------------|--------------------------------------|---------------------------------------|-----------------------------|------------------------------|--------------------|
| Lyulinorskaya, Talitskaya   | 793-1104                             | 1.50                                  | 1.35                        | 1.21                         | 1.52               | 711                |

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The main factors influencing the initial properties of cement slurries/hardened cement slurries are: geological, physical and hydraulic conditions for casing strings cementing, natural and plugging properties of Portland cements, hermodynamic and physicochemical non-stationary interaction processes between slurries and near wellbore formation zones (permeable and unstable). The joint and simultaneous impact of these factors stipulates well casing procedural violations and decreases well integrity indicators. A review of the works relevant to the considered issue has shown that the stabilization (integrity) of the initial properties of well slurries and the formation of a uniformly dense hardened cement slurry in the annular space along the sealing intervals is one of the main and still unsolved technological problems.

Widely used in practice, modern technologies of physicochemical regulation of the properties of well slurries, as well as technical means of sealing the annular space are of low efficiency. The current situation is due to the fact that the majority of methods do not take into account the very reason of prevailing influence on the stability of initial properties of cement slurries – their hydraulic connection with a complex of permeable rocks formations, both while moving within the annular space and during the period of cement slurry thickening (CST).

In the conditions of nonstationary hydrodynamic interaction of a cement slurry with a complex of fluid-saturated formations, accompanied by a vibrowave (turbulent) motion of the former in the annulus space during the casing strings cementing, there is an acceleration of the processes changing the initial water to cement ratio (W/C) of the cement slurries. Moreover, neither in the dynamic stage of the cementing process...
nor during the CST period, these W/C changes are not controlled but unambiguously identified after the formation of the cement sheath in the annular space by its density, using a SDGRDFD (Selective Down hole GR-Density Fault Detector).

In the context of the Cement Bond Log (CBL) (see the Figure) and the relevant calculations, consider the hydraulic properties of the casing string cementing and the characteristic types of turbulent flows for various cement slurries (gel-cement slurry and Portland cement slurry) in the annular space.

A real-time CBL analysis of the changes in the production string cementing parameters allows to identify a number of properties of the hydraulic and temperature conditions of the cementing operations. The main property is the discontinuity in the cement slurry flow and the turbulent (vibrowave) type of its motion in casing strings and annular spaces. This is explained by the action of the gravitational forces affecting the fluid flows of various density in vertical or inclined channels (wellbore).

The gravitational motion type of drilling and grouting fluids in a well with a discontinuity in the flow is observed when a critical height of grouting fluid is reached in the casing, and hydrostatic pressure in which exceeds the hydrostatic pressure of drilling fluid in the annular space (see Position 1).

I – pumping a gel-cement slurry; II – pumping a cement slurry; III – displacement; 1 – beginning of the cementing process; 2 – discontinuity of the liquid flow in the casing; 3, 4 – pumping a gel-cement slurry, ρ₁ = 1.50 g/cm³; 5 – pumping a cement slurry, ρ₂ = 1.83 g/cm³; 6 – temperature regime of slurry circulation; 7 – restoration of continuity in flows of technological liquids; 8, 9 – well integrity failure; 10 – shut-off pressure

Figure. The CBL of production string cementing of a well at the Sarymo-Russkinskoye oil field.

In the mentioned case, this happened 27 minutes after pumping of 14.3 m³ of gel-cement slurry with a density of 1500 kg/m³ into the casing, when the height of the
slurry column reached 635 m (see Figure 1). Since that moment, the pressure at the well head was decreasing from 2.2 MPa to almost atmospheric (see Fig. 2), and remained unchanged until the restoration of flow continuity of the displacement fluid and the cement slurry, while the latter was reaching its designed height (see Fig. 7, 8). During all this time period – 2 hours 23 min. (see positions 2, 3, 4 and 7), the proceeding of cementing process was spontaneous and uncontrolled, on reaching the maximum values of the cement slurry fill-up rate in the annular space and hydrodynamic pressures on the walls of the wellbore. During this period, there most likely are: partial absorption of cement slurries by the permeable rock formations, hydraulic fractures, fluid shows.

At this time, the hydraulic properties of the casing cementing process is characterized by the continuous and discontinuous gravity flow of a cement slurry in the annular space – with an evacuated space in the casing strings. When injected into the pipe, the flow of the cement slurry becomes discontinuous when entering casing strings, and in such condition it moves down hole to the depth of the current liquid level, with no pressure indication on the wellhead pressure gauge. And this continues until the restoration of the continuity in the flow of process fluids, identified by an increase of pressure indications at the wellhead (see Fig. 7). During this latent period of casing cementing, the processes of hydromechanical interaction of cement slurries and fluid-saturated formations are intensified. And one of the significant consequences of these processes is the change in the initial density of the cement slurry (Table. 1).

Later on, more significant and irreversible changes in the initial properties of cement slurry and hardened cement slurry occur within the SCT period, during the relative thermodynamic equilibrium in the well.

The quality of casing strings cementing in production wells of oil fields in Western Siberia was assessed using the Selective Gamma-Gamma Logging research method (SDGRDFD data). An analysis of the data has shown that the change in the density of cement slurries/ hardened cement slurries in the annular space takes place all along its lifting height. The length of the intervals varies from 3.0 to 1425 m, while the average density of gel-cement slurries varies within the limits of 1.244-1.52 g/cm$^3$, decreasing in some sections to 1.17-1.3 g/cm$^3$. The density of cement slurries is slightly higher: 1.27-1.48 g/cm$^3$, sometimes reaching 1.27-1.99 g/cm$^3$. Dependence of cement slurries form their densities is shown in Table 2.

| Grade of cement | W/C ratio | Nominal water loss, cm$^3$, 30 min. | Density, g/cm$^3$ | Water gain, ml | Spreadability, mm | Cement strength, bending | shortening |
|-----------------|-----------|-----------------------------------|-------------------|----------------|--------------------|-------------------------|------------|
| PTsT Ts-50 (ПЦТ Ц-50) | 0.45 | 139.04 | 1.86 | 0 | 180 | 4.93 | 15.6 |
It should be noted that such well cementing results noted in Western Siberia are characteristic of the vast majority of oil and gas fields in our country and abroad.

Based on the results of the presented research data, it can be concluded that for such a complex natural and technical system as "well - casing support" the use of traditional cementing technologies that are relevant to their thermodynamic application conditions, currently has no prospects. In this regard, in order to successfully solve this complex technological problem of extreme difficulty, it is necessary to involve systematic scientific and technical approaches and solutions.

### III. Development of the Multi-Technology Complex of the Wellbore Hydrodynamical Hardening

In order to effectively solve the key technological problem of well drilling (stabilizing the technical condition of the uncased wellbores and the hydraulic drilling conditions; preserving the natural reservoir properties of productive formations; forming a long-term sealed casing support and wellbore screen), the Multi-technology Complex of the Wellbore Hydromechanical Hardening (KMGUS) has been developed.

The methodological basis for the research is the synchronization (simultaneity) of well drilling and the hydromechanical hardening of wellbores by jetting out a drilling fluid at wellbore walls. The formation of the near-wellbore waterproofing screen takes place under the influence of the kinetic energy from a jet of a hydraulic motor, which is transformed into a field of quantum high-amplitude low-frequency pressure pulses. The thermodynamic process of waterproofing is characterized by the following indicators and parameters of technological impact: the impact of a jet is 0.15-0.40 t, the time of contacting with the rock is 0.012-0.017 s, and the temperature of the colmatizing medium is 500-600 °C (approximately).

Formed in these conditions, a near-wellbore waterproofing screen is characterized by the following technical indicators: the thickness of the adhesive layer on the wellbore walls is 2-3 mm; the depth of the colmatation zone in the matrix of permeable rocks.
is 10-30 mm; the gradient of the hydromechanical strength of the wellbore with overburden on formation is 0.018-0.025 MPa/m, with under burden on formation is 0.010-0.012 MPa/m. When drilling wells in the interval of installation of service and operational casing, the hydromechanical hardening of the wellbore ensures the implementation of the following technological effects, as well as qualitative, technical and economic indicators of well construction:

- optimization of hydraulic drilling conditions, casing cementing and prevention of problems;
- maintaining initial properties of cement slurries/hardened cement slurries;
- protection of casing strings and hardened cement slurry against corrosion;
- increase of tightness and durability of casing support;
- fold reduction in funds and time required for drilling and of casing support installation per a wellbore interval;
- stabilization of the cementing processes in the production string and formation of cement sheath;
- selective isolation of productive beds from non-productive ones in intervals of productive strata;
- prevention of possible emergency situations (gas and oil-water shows, absorption, emissions and fountains) and well water flooding;
- protection of casing strings and hardened cement slurry against corrosion;

While completing wells at a number of fields in various regions of the country, a non-linear enhancement of key quality and efficiency indicators has been achieved, both during the initial drilling of productive stratum and during the long-term operation of these wells. The generalized drilling performance indicators have shown the following result: growth of drilling performance indicators by 20-25%, a 1.6-3.0-fold increase of current production rate, a 2.0-2.6-fold decrease of water cut in the extracted product.

Thus, as the field experience shows, the use of KMGUS in drilling and completion of oil and gas wells in various geological and technical conditions appears to be highly economically promising. KMGUS excludes various problems in constructing oil and gas wells, as follows: absorption rates higher than 50 m³/h, gas-oil-water shows, hydraulic fractures and instability of the exposed rock formations, kicks and blowouts. Fluid shows and cross flows are also prevented during well operation processes. Production rate of wells developed with the use KMGUS are 2 and more times higher in comparison with traditional well construction technologies, water cut in the extracted product is lower by more than 2 times, and as a result of KMGUS-based well operation, the non-linear growth of final ORF indicators.
IV. Conclusions

In summary, it has been noted that KMGUS maintenance costs are comparatively low (do not exceed 1000-1500 thousand rubles), high quality and efficiency of drilling operations and environmental safety.

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