Improvement of the well cementing technology, increasing the reliability of the annule isolation and preserving the permeability of the reservoir

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Abstract. The article presents measures to improve the quality of cementing the production string of high-performance wells. The relevance of the proposed technological solutions is substantiated. The results of experimental studies of the installation simulating the processes occurring during the thickening of the cement slurry under the action of gravitational forces are presented. An algorithm for creating overpressure on the wellhead during fastening of the production string is proposed. The compositions of process fluids are described, which increase the reliability of the annular space isolation and preserve the permeability of the reservoir, and provide the main data on the results of their laboratory studies. For cementing the annular space of the production string, the composition of the expanding cement slurry has been developed and the procedure for its preparation has been established. The proposed solution has low water separation and high sedimentation resistance; has adjustable rheological parameters. Cement stone is characterized by low gas permeability and high strength properties.

1 Introduction

The development of technological processes, the improvement of technical means and technologies for well completion, aimed at reducing material and energy costs, increasing reliability and durability, and maximizing the preservation of the reservoir properties of productive formations, are of great economic importance.

The creation of wells with high flow rates makes it possible to increase the reliability of the functioning of the unified gas supply system of Russia. The study of the effect of increasing the rate of gas extraction on the amount of gas recovery from the formation showed that this is due not only to geological and technological factors, but also to the use of highly productive wells. During the construction of which the main tasks are: ensuring maximum gas extraction and reliability of the well as an engineering and technical facility; high quality well lining; maintaining the permeability of the reservoir; economic profitability.

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However, a feature of the design of highly productive wells is the large diameters of the production string, which causes the problem of completeness of the annular space filling and does not allow achieving high cementing efficiency using traditional technologies due to the formation of gas-conducting channels in the cement stone, leading to depressurization of the annulus. In this regard, the need to develop and implement an integrated approach to the construction of high-performance wells is obvious.

Completion of well construction is one of the main and technologically complex processes that cover the entire cycle of work from the beginning of the opening of a productive formation by drilling and to putting the well into operation.

Maximum gas extraction can be achieved through the use of a rational design of the bottomhole formation zone (BHZ), which provides the maximum gas inflow area and increased drawdown during operation; at the same time, the use of an increased diameter of the production string (≥ 168 mm); creating a tight lining of the production string, necessary to prevent interlayer cross-flows and annular casing pressures.

The reliability of the well as an engineering structure can be ensured by equipping the bottomhole zone with special filters (frameless slotted ones), while the design of the production string must ensure the stable operation of the well in the planned modes without self-damping and the formation of sand plugs. And the use of special formulations of cement slurries should ensure the formation of a cement stone resistant to destruction under the influence of alternating loads, aging and corrosion throughout the entire period of operation.

It has been established that when the BHZ is chemically fixed with binders, the pore space interval is partially filled with hardening products and the reservoir permeability decreases. In this regard, when strengthening the cemented sandstone of the flooded BHZ interval, an important criterion for optimizing the strengthening is not only to ensure the strength of sand fixation, but also to maintain the filtration characteristics of the treated interval [8, 9].

2 Materials and Methods

The scientific basis of this study is the proposed algorithm of technological solutions, namely the creation of excess pressure on the wellhead during the fastening of the production string. The composition of the expanding cement slurry has been developed and the procedure for its preparation has been established. Under the conditions of the experimental base of JSC "SevKavNIPigaz", a unit was created that simulates the processes that occur during the thickening of the cement slurry under the action of gravitational forces. With the help of this installation, studies of a special liquid were carried out.

The study is based on statistical data, materials of scientific conferences, seminar data, printed materials, etc., highlighting current trends in the use of well cementing technology.

3 Results

According to the results of the theoretical and experimental studies, the specialists of JSC "SevKavNIPigaz" developed a technology for cementing the production string, which is the following sequence (Figure 1): the production string is lowered below the roof of the reservoir and cemented with two portions of cement slurry with different setting times. In this case, the lower portion consists of an expanding mortar with short setting times, the upper portion of a mortar with long setting times. A special fluid is installed at the mouth. Before running the production string, it is proposed to fill the reservoir interval with a gel-forming composition [1].
Fig. 1. Scheme of cementing the production casing of an open-hole well.

The gel-forming composition prevents the penetration of cement slurry into the reservoir and provides temporary isolation of the reservoir from the wellbore, while maintaining its natural permeability. The component composition of the gel includes: structurant, crosslinker and filler. The filler in the composition of the solution acts as a colmatant of the pores of the productive formation. In order to expand the range of application of the resulting gel for various mining and geological conditions, three fillers were experimentally selected that differ in chemical nature and dispersion (corded basalt and polypropylene fiber).

The gel-forming composition has the following properties: manufacturability (the set of the structure must occur without shutting down the well); homogeneity; gas isolation of the annular space; inertness to the rocks that make up the reservoir; environmental friendliness of components; is easily removed from the specified interval after cementing operations during flushing and development of the well without reducing the porosity and permeability properties (PPP) of the reservoir. The system is selected taking into account the formation of the maximum strength of the structure before the cementing of the production casing and retains its properties for the entire period of application.

In the course of experimental studies [2], it was determined that the composition for temporary blocking of the productive formation has a high adhesive ability (Figure 2a) and sufficient gel strength, which makes it possible to cut off the productive formation from the
penetration of cement slurry during cementing and prevent the migration of formation gas into the hardening cement slurry solution during WOC (Figure 2b).

Fig. 2. Study of the developed gel-forming composition for technological properties.

To study the gel-forming composition for gas holding capacity and for contact strength with rock and metal, tests were carried out. With the help of the experimental setup, the coefficient of permeability recovery and the plugging coefficient were determined on artificial and natural samples of core material (Figure 3).

In turn, a special fluid transfers excess pressure to the cement slurry to prevent gas penetration during the formation of the cement stone structure, and also provides back pressure to gas formations in the presence of through defective channels in the cement stone during well operation.

The special liquid consists of a density regulator, a filtration reducer, a structurant, an antifreeze additive, and a reducer of structural-mechanical and rheological parameters.

\[
\beta(K_0, \tilde{C}) = 15.25 \cdot \tilde{K}_0^2 \cdot \tilde{C}^2 + 1.92 \cdot \tilde{K}_0^2 \cdot \tilde{C} - 2.25 \cdot \tilde{K}_0 \cdot \tilde{C}^2 - 25.38 \cdot \tilde{K}_0^2 - 4.25 \cdot \tilde{K}_0 \cdot \tilde{C} - 15.50 \cdot \tilde{C}^2 + 1.50 \cdot \tilde{K}_0 - 20.17 \cdot \tilde{C} + 88.88, R = 0.913
\]

Fig. 3. Change in the core permeability recovery factor (\(\beta\)) on the content of bridging filler (C) and depending on the initial core permeability (\(k_0 = 0.2\text{-}1.0 \, \mu m^2\)).
4 Discussion

Under the conditions of the experimental base of JSC "SevKavNIPIgaz", a unit was created (Figure 4) [3], simulating the processes that occur during the thickening of the cement slurry under the action of gravitational forces. With the help of this installation, studies of a special liquid were carried out.

From the experiment it was determined that the value of the pressure drop due to suspension of the solution is numerically small and does not exceed 200 Pa per meter of column. For an underground gas storage well, this is approximately 0.05 MPa. It follows that the selected composition of the liquid does not have the properties of "hanging". Also, after a day, an overpressure simulation was carried out at the experimental installation by gas injection. It was revealed that the dependence of the change in bottomhole pressure on the increase in excess pressure has a stable linear character. In this case, the change in wellhead pressure is completely transferred to the bottom hole.

The special fluid has:
- sedimentation stability and aggregate stability for the entire period of well operation;
- density range 1,150 – 1,600 kg/m³;
- low values of static shear stress;
- high spreadability;
- inertness to casing metal and process equipment.

![Fig. 4. Scheme of an experimental setup for modeling the process of cement slurry setting in a well.](image)

For cementing the annular space of the production string of high-performance wells, the composition of the expanding cement slurry has been developed and the preparation
procedure has been established. Portland cement grade PCT I-G-CC-1 [4] was chosen as the basis of the grouting slurry, and DRS-NU was chosen as an effective expanding additive. Additionally, the cement mixture is treated with a filtration reducer, a setting accelerator and a defoamer.

Cement stone without DRS-NU additive is shrinkable (Figure 5), when it is introduced in an amount of 0.5-2.0 wt. % cement stone varies slightly in volume and is optimal for cementing the annular space of the well. A noticeable expansion begins with an increase in the content of the additive in the dry mixture by more than 4 wt. % and recommended for filling the annulus [5].

![Fig. 5. Volumetric change in the cement slurry-test from the content of the additive DRS-NU.](image)

The developed composition has low water separation and high sedimentation stability; has rheological parameters that meet the specified cementing conditions, short setting times, low gas permeability; strength characteristics of cement stone by the end of the WOC are 5-7 MPa in bending and 14-16 MPa in compression [6].

5 Conclusions

Thus, as part of the improvement of production string cementing according to the technology of JSC SevKavNIPIgaz, it is recommended:

- Application of an algorithm for creating excess pressure on the wellhead, which compensates for the “hanging” of the cement slurry column during its structure formation.
- Joint use of a special non-hardening fluid in the annulus to control the bottomhole pressure during cementing and a gel-forming composition to temporarily block the bottomhole zone in order to block the gas inflow channels. It has been established that the composition of the special fluid has a wide density range of 1150-1600 kg/m³, has low filtration rates and static shear stress, is aggregation-stable for a long time. At the same time, the developed composition for temporary blocking of the BHZ retains the natural permeability of the reservoir, has sufficient gelation time to transport the solution in a given interval, and is removed during release by flushing the well and during development.
- Application of the developed composition of the expanding cement slurry, obtained due to the synergistic effect in the qualitative and quantitative selection of components in order to achieve properties that meet the requirements of the developed cementing technology.
In order to compensate for the decrease in bottomhole pressure during the WOC period due to the structure formation of the cement slurry, experimental studies were carried out, which are widely presented in the works [3, 5, 6]. The conducted set of experiments and the analysis of scientific and technical literature made it possible to develop an algorithm for creating excess pressure in the annular space, included in the Measures developed by JSC "SevKavNIPgaz" to improve the quality of well cementing. Since 2009, these Measures have been successfully implemented in the cementing of production strings of high-performance wells of the Nevsky UGS [7], which was reflected in their use in the development of the normative document Recommendation Gazprom.

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