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Development of spacer fluids and cement slurries compositions for lining of wells at high temperatures

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Article is devoted to creation of new compositions of process solutions for lining of directional wells at high temperatures. Developed compositions provide high durability characteristics of cement stone. It is shown that with an increase in packing density of cementing slurry components durability characteristics increase and porosity and permeability of cement stone decrease, whereas an increase in temperature and pressure leads to a significant increase in compressive and bending durability, which is associated with presence of quartz in them.

It has been established that introduction of special structure-forming additives to the composition of developed cementing solutions allows formation of sedimentation-resistant cement systems that can provide an increase in durability characteristics of cement stone and, in general, quality lining of directional wells. Study of rheological properties of developed cementing compositions showed that the systems have high yield strength at increased temperatures and pressures.

Developed compositions of water-based spacer fluids increase the cleansing degree for both casing and rocks surfaces from mud and clay cake residues, which improves the cementing quality of oil and gas wells.

Mechanism for increasing the washing ability of spacer fluids and durability characteristics of cement stone, depending on composition and properties of their constituent components, is disclosed.

Key words: cementing; packing density; directional well; cement stone expansion; sedimentation stability; spacer fluid; washing ability

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Introduction. High-quality lining of directional wells is ensured by use of spacer and cementing fluids, composition of which increases the degree of clay cake removal from wellbore and annulus integrity. Large amount of research has been performed in this regard [2, 6-9], however, little attention has been paid to effect of increased temperatures and pressures on properties of solutions. Therefore, aim of this work is to develop the composition of process fluids (spacer and cementing), providing an increase in sedimentation stability of cement slurry, durability of cement stone and its adhesion to rocks and casing, which leads to an increase in the quality of directional wells' lining in conditions of high pressures and temperatures.

Methodology and discussion. Based on requirements for material, designed for cementing directional wells at high pressures and temperatures, basic cementing compositions have been developed:

Solution sample	Components of composition, %
1	PCT-I-100 (70), quartz sand (5), hematite (25)
2	PCT-I-100 (65), quartz sand (15), hematite (20)
3	PCT-I-100 (70), quartz sand (10), hematite (20)
4	PCT-I-100 (70), quartz sand (15), hematite (15)
5	PCT-I-100 (65), quartz dust (15), hematite (20)
6	PCT-I-100 (70), quartz dust (5), hematite (25)
7	PCT-I-100 (70), quartz dust (10), hematite (20)
8	PCT-I-100 (70), quartz dust (15), hematite (15)

In these compositions, quartz sand and quartz dust provide high durability characteristics of cement stone, especially at high temperatures, and hematite – high density of cement slurry. Introduction of magnesium oxide into these compositions contributes to expansion of the cement stone and increase of its adhesion characteristics to steel, inclusion of a plasticizer (lignosulfonate) pro-

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vides control of the cement slurry mobility, and introduction of a polymer (hypane) and a structure-forming additive (kaolinite) helps to create solutions that are resistant to sedimentation.

Determination of optimal packing density of the cement composition was carried out using mathematical model of Tufar [16].

Analysis of the results (Fig.1) shows that compositions 1, 2, 5, and 6 are optimal according to the value of the packing density and are selected as a base for further study. It is expected that high packing density of these systems will increase durability characteristics and reduce porosity and permeability of cement stone [1].

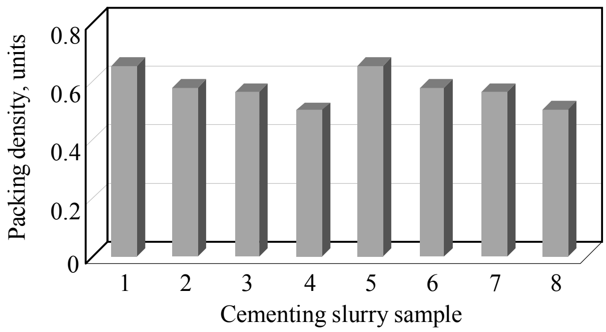

Fig.1. Packing density of developed cementing slurries

In order to eliminate precipitation of solid phase on lower wall of the wellbore and formation of water channels at upper wall during cementing directional wells, sedimentation-resistant cement slurries should be used [8]. In the investigated base compositions (1, 2, 5, 6), this property is ensured by introduction of hydrolyzed polyacrylonitrile (hypane) and kaolinite into them. Polymer helps to increase viscosity of the system and form adsorption shells on surface of solid phases, as a result of which total density of the system decreases, and, consequently, sedimentation rate decreases [5, 11]. Structure-forming additive of kaolinite gives the solution thixotropic properties. Kaolinite content in all base mixtures was 1 %, and amount of hypane increased from 2.25 to 2.5, 3.0, and 3.25 % of dry mixture in compositions 5, 6, 1, and 2, respectively. All developed cementing solutions had zero water loss at the indicated polymer and kaolinite concentrations.

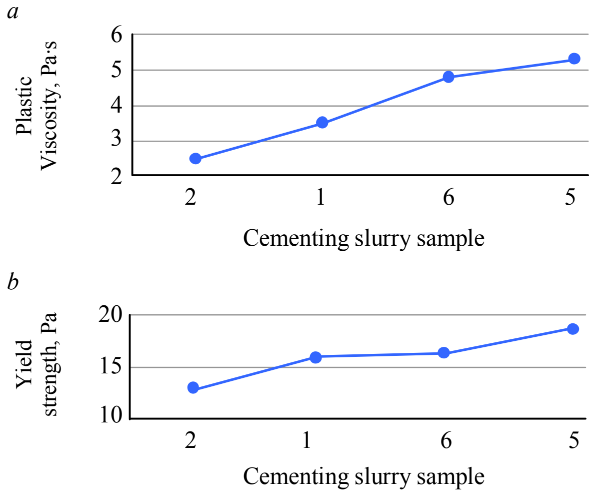

Fig.2. Dependence of plastic viscosity (*a*) and yield strength (*b*) on cementing slurry composition

However, presence of polymer in solutions can lead to their low mobility and limited use. Therefore, lignosulfonate (0.5-1 % by weight of the binder) added to the base cementing solutions was chosen as a plasticizer [13]. Effect of additives used in the cementing compositions on their rheological properties was studied under conditions of high pressures and temperatures (P = 1.38 MPa, T = 170 °C). Results of the study (Fig.2) show that the systems have high yield strength at increased temperatures and pressures. Properties of the base composition 5 turned out to be better than the rest, due to its high packing density and degree of mobility.

To ensure reliability of well lining during entire operational period, cement stone should have high durability characteristics during well construction at high pressures [12]. Durability characteristics were studied on mixture samples 1, 2, 5, and 6 under normal conditions, as well as at a pressure of P = 4 MPa and a temperature of T = 160 °C. According to presented results (Fig.3) it can be said that cementing compositions with high density and compact packing (5 and 1) under normal conditions are more durable during compression and bending tests. An increase in temperature and pressure leads to an increase in their compressive durability by an average of 33 % and bending durability by 25 %, due to presence of quartz sand (compositions 1 and 2) and quartz dust in composition 5. Under normal conditions, quartz is practically an inert component, and at increased temperatures it actively reacts with hydrosilicates, hydroaluminates and calcium hydroxide. Under these conditions, more stable crystalline hydrates form [15, 17].

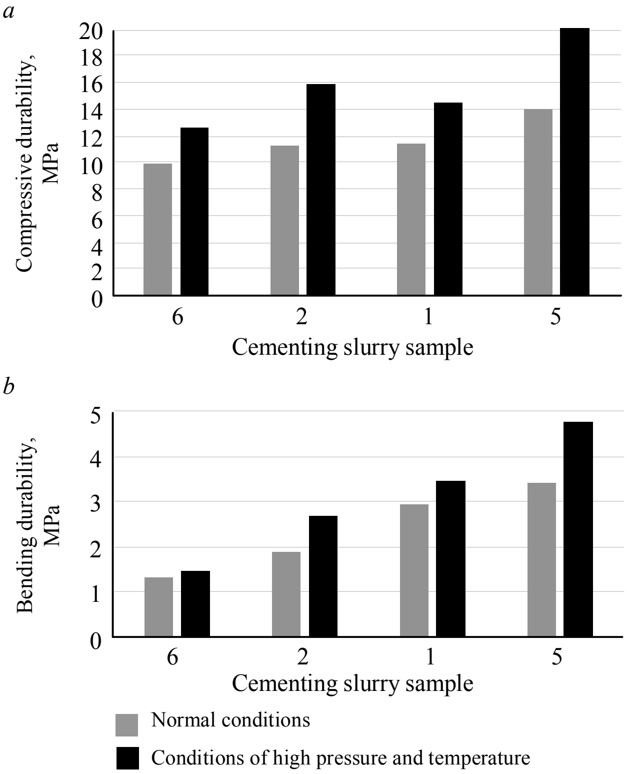

Fig.3. Compressive durability (*a*) and bending durability (*b*) of cementing samples of various compositions

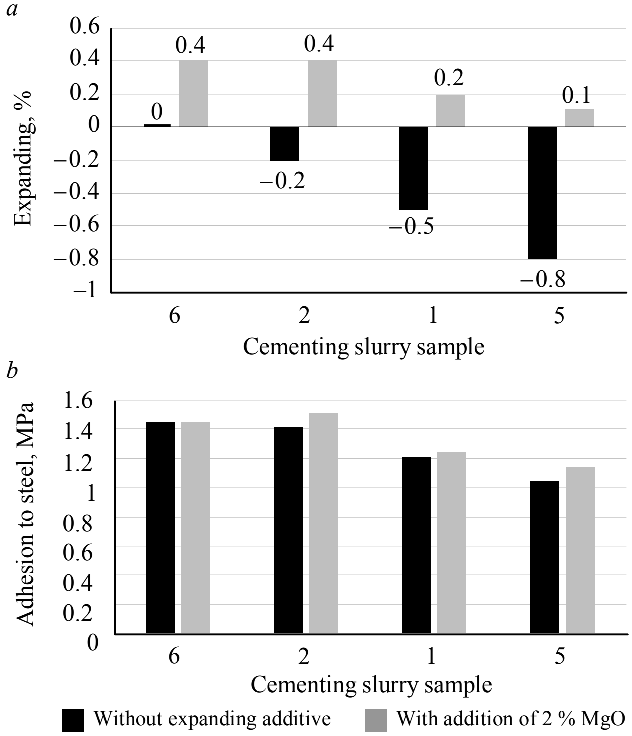

Fig.4. Cement stone expansion dependence after two days (a) and its adhesion to steel (b) on composition of cementing mixture

Low adhesion characteristics and shrinkage of cement stone during hardening lead to a lack of good adhesion to the casing and the walls of the well. Therefore, magnesium oxide (MgO) was used as an expanding additive in developed cementing compositions. Results of study, dedicated to determining the adhesion of cement stone to steel and its expansion, show (Fig.4) that cementing composition 5, which has the highest packing density, also has the highest shrinkage deformation. Introduction of magnesium oxide additive in an amount of 2 % by weight of dry cement mixture contributes to expansion of cement stone to an average of 0.3 %, as well as to an increase in its adhesive characteristics to an average of 5 %. However, an increase in MgO content of more than 2 % can lead to a decrease in the durability characteristics of the stone, which is typical for most expanding additives [3].

Quality of well cementing is also significantly affected by degree of drilling mud displacement from the annulus, which is enhanced by the use of special spacer fluids. In most cases, water treated with various types of surfactants is used as a spacer liquid. Under conditions of high pressures and temperatures it is not able to perform its functions [4, 6, 10]. For this, formulations of weighted spacer liquids were developed and their washing ability was investigated. Compositions and density of spacer fluids:

Composition sample	Components of composition, %	Density, kg/m^3
1	Water (57), hypane (7), hematite (36)	1600
2	Water (59), hypane (8), hematite (33)	1550
3	Water (59.5), CMC (0.5), hematite (40)	1750
4	Water (65.9), CMC (0.5), hematite (30), hypane (3,6)	1500

Introduction of hematite in the composition of the spacer fluid can significantly increase density to 2600 kg/m^3, which is necessary to ensure hydrostatic equilibrium in the wellbore-formation system [18].

Washing ability of spacer fluids depends on their composition and is determined by cleansing degree of the casing surface from drilling mud residues and removal of clay cake from the walls of the borehole and cement stone.

Developed weighted spacer fluids contain 0.5 % of various surfactants: OP-10 (non-ionic class), AB catamine (cationic class) and sodium dodecyl sulfate (anionic class). Analysis of Fig.5 shows that compositions of spacer fluids containing hypane as a polymer (1 and 2), have a greater washing ability than the rest. Compositions 3 and 4 containing CMC have high viscosity, which reduces their effectiveness.

Spacer fluid of composition 2 containing OP-10 was additionally tested for its ability to remove clay cake from different surfaces. It was experimentally established (Fig. 6) that efficiency of removing residual drilling mud from surface of rocks is on average 25 % less than from surface of the casing string's metal. This is due to strong roughness of the rocks, which reduces the washing ability of the spacer fluid.

It is known that introduction of quartz sand into the composition of the spacer fluid can facilitate the transfer of the process fluids' flow regime in the annulus from laminar to turbulent [2, 14]. Therefore, influence of additives up to 5 % quartz sand on washing properties of spacer fluids with a 0.5 % concentration of OP-10 was evaluated (Fig.7).

Presented results show that presence of quartz sand in the spacer liquid increases it's washing ability by an average of 10 %, which is caused by turbulence in the flow at low speeds.

Conclusion. As a result of experimental study, composition of the process fluid was substantiated, which allows improving the quality of directional wells' lining at high pressures and temperatures. Developed cementing mixture is optimal in terms of its basic structural and rheological, physical and mechanical properties and includes Portland cement PCT I-100, quartz dust, MgO, hypane stabilizer, lignosulfonate plasticizer, hematite weighting agent and kaolinite structure-forming additive.

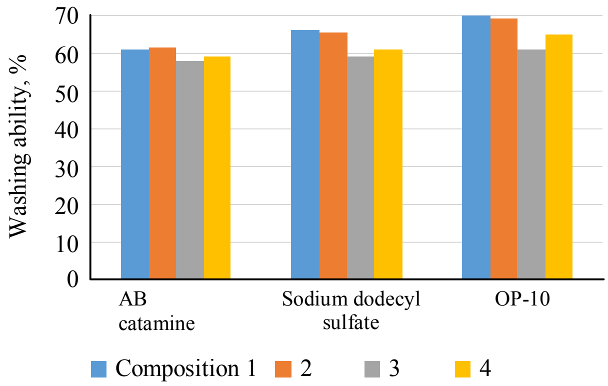

Fig.5. Dependence of weighted spacer fluid's washing ability on type of surfactant used

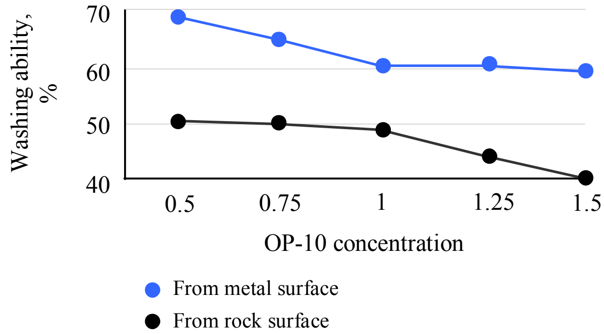

Fig.6. Dependence of the spacer fluid's washing ability with composition 2 on concentration of surfactants

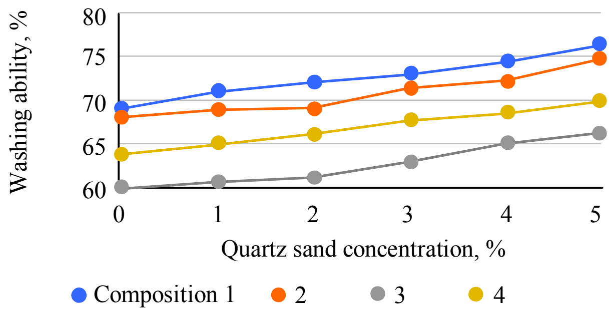

Fig.7. Influence of quartz sand additive on the washing ability of the spacer fluid

Developed water-based spacer fluid, which includes hypane, hematite, OP-10 and quartz sand, helps to increase degree of drilling mud displacement and its replacement with cement, and also helps to remove clay cake from the surface of the wellbore.

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