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VISCOELASTIC SYSTEMS FOR WELL CONSTRUCTION

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One of the most important factors that ensure the required quality of well casing is the use of effective flushing fluids, among which viscoelastic systems should be singled out, providing the best displacement of drilling fluid during the cementing process.

The article considers the mechanism of polymerization of the viscoelastic systems when using polyacrylamide, cross-linked with the polyvalent metal cations, and the prospects for using these systems for well casing. Models of the flow of the viscoelastic systems and their differences due to the presence of normal stresses in the viscoelastic systems are shown. The justification of the component composition of the viscoelastic systems and their main properties, which ensure the effectiveness of these systems as the flushing fluids, is provided, and the research devices are described.

It has been experimentally confirmed that it is necessary to use additives with the highest degree of oxidation, which increase the rate of strength gain when choosing a polyvalent cation as a "crosslinker" for the viscoelastic systems. The most rational ratios of components are experimentally substantiated, and the best holding capacity of the viscoelastic flushing fluid is proved in comparison with the other types of spacers, which excludes the flow of cement slurry down in the well annulus after the completion of the cementing process.

The best degree of cleaning the wellbore in the zones of caverns with a laminar flow regime has been proven on the original installations. To minimize the negative effect of polymer films from the viscoelastic systems on the adhesion of cement stone to casing strings, it is recommended to pump a portion of a fluid, containing a polymer destructor, after a portion of a viscoelastic flushing fluid.

Key words: flushing fluid, annulus, viscoelastic systems, polymer, rheology.

Introduction

Flushing fluids are indispensable process fluids for cementing any wells [1–4]. Flushing fluids pumped in prior to the cement slurry prevent mixing with the drilling fluid, and prevent degradation of the systems to be separated. The most important function of the flushing fluids is to increase the efficiency of cleansing fluid removal from the caverns, i.e. to increase the degree of substitution of the cleansing fluid with cement. In addition, the flushing fluids should remove the filter cake from the well walls, wash the mud film from the casing string walls, and perform many other functions.

Naturally, the flushing fluids should have a number of properties for efficient operation, among which the most important ones are the rheological characteristics, density, etc. [5, 6].

Among many types of flushing fluids, viscoelastic systems (hereinafter referred to as the “VES”) attract special attention, which have gained great popularity in the oil and gas industry, including the construction of wells, where they are used to remove cuttings in horizontal wellbores. However, the VES have been most widely used as flushing fluids for well casing.

On the mechanism of the VES polymerization

The VES are the polymer solutions, which are a polycondensation network structure, crosslinked with the polyvalent metal ions [7]. Due to the structure, formed by the chemical bonds, the system has both the viscous and elastic properties due to the presence of normal stresses during the fluid movement. This system does not obey the usual models and laws of the fluid movement, which provides unusual results in the study of this system [8–10].

Among the most distinctive features of the viscoelastic systems, one can single out the presence of normal stresses in them, which manifests itself, for example, in the Weisenberg effect, the essence of which is that when a paddle mixer rotates in a viscoelastic fluid, the VES “creeps” up the rod, while in the traditional viscous or viscoelastic fluids, a funnel is usually formed [11].

It is the presence of normal stresses, that provides this type of fluids with the unique properties, which ensure their high efficiency in the well construction processes [12, 13].

The VES have the intermediate properties between the polymer solutions and rubber-like bodies. Due to the network, formed by the chemical bonds, they are characterized by finite elastic deformations.

Polycondensation occurs due to the “crosslinking” of the polymer macromolecules with polyvalent metal ions. The crosslinking rate can be controlled by the salt content, the pH of the medium, and at high temperatures, by the addition of reagents, which slow down the crosslinking process. The substances, which form a water-soluble complex or chelate compounds with metal ions are used as moderators for crosslinking. The thermal stability of the cross-linked gels is different, therefore, depending on the required temperature, one or another metal ion or their mixture is chosen. The mechanism of the interaction of the polymeric reagents (polyacrylamides (hereinafter - PAA), polysaccharides, biopolymers) with a polyvalent cation consists in the fact that when the polyvalent metal cations are introduced into the polymer solution, bridge bonds are formed between the macromolecules, as a result of which the latter lose their kinetic independence, and the resulting system loses its ability to irreversibly deform (flow). In the process of gelation, the polymer macromolecules in the presence of the polyvalent metal ions form a three-dimensional network structure of high mechanical strength, inside which a fluid (water) is immobilized. The mechanism of gelation includes the formation of cross-links between the neighboring macromolecules through the interaction of free carbonyl, carboxyl and hydroxyl groups of polymers with the polyvalent metal ions.

At the same time, after the use of the VES as a flushing fluid, a polymer film remains on the walls of the casing string and the well walls, which reduces the quality of a contact between the cement stone and the limiting surfaces. Ultimately, this may manifest itself in the deterioration of the results of the acoustic cement bond logging. In this regard, it is important to know the effectiveness of various VES destructor reagents in order to use them as part of a portion of the flushing fluid, injected after the VES.

The acid-type destructors are considered in [14], the mechanism of action of which is based on lowering pH and breaking the bonds, formed by polyvalent metals. Sulfuric acid, hydrochloric acid, and citric acid, sulfamic, acetic and oxalic acids have been considered as destructors [14]. At the same time, it has been shown that the main action of the destructors is directed more towards the destruction of the bonds of metal ions than to lowering the pH of the medium. In addition to acids, there are several more types of destructors, for example, hydrogen peroxide, oxidizing agents, and enzymes.

Theoretical aspects of the VES rheology

The first models for a viscoelastic material were proposed by D.T. Maxwell (Fig. 1) and T.W. Kelvin (Fig. 2) [8]. The Maxwell model is a spring and a damper connected in sequence, and in this model, the stress is the same in each element, and the total deformation is equal to the sum of the deformations of the damper and spring.

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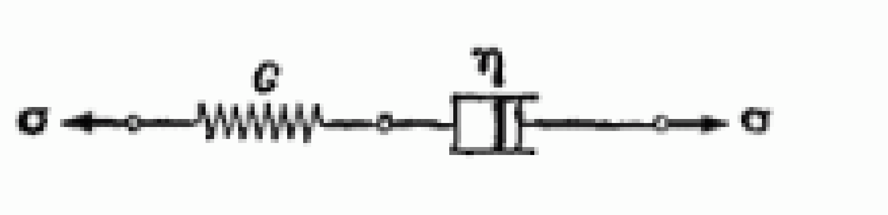


Figure 1. The Maxwell Model

The relationship between the stress and strain for the Maxwell model is described by the formula (1):

$$\frac{\sigma}{G} + \frac{\sigma'}{\eta} = \varepsilon \qquad (1)$$

The Kelvin model is a parallel connection of a spring and a damper, while the deformations in each element are the same. The total voltage is equal to the sum of the voltages on the both elements (Fig. 2).

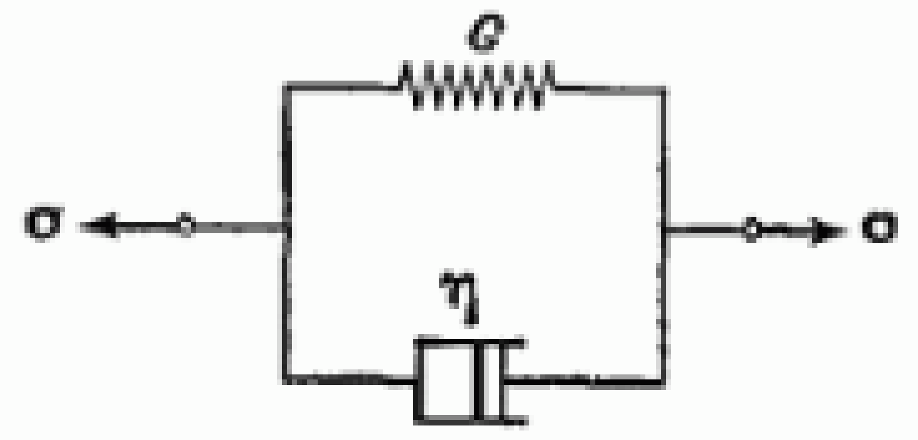


Figure 2. The Kelvin model

The relationship between the stress and strain for the Kelvin model is described by the formula (2):

$$\sigma = G\varepsilon + \eta e \qquad (2)$$

However, the subsequent studies of the VES have shown that the simple Maxwell and Kelvin models do not provide an accurate description of the movement of the real VES, and, therefore, more complex combinations of the “spring – damper” models are required.

In particular, the three- and four-parameter models are known. The latter is already able to describe the 3 main types of the medium behavior, since it combines an instantaneous elastic reaction due to a spring, and the flow of viscous fluid of the three-parameter model (Fig. 3) [8].

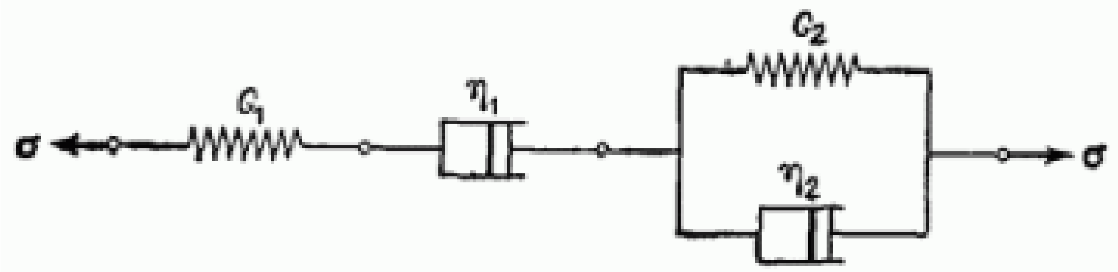


Figure 3. A four - parametric model of the viscous fluid

To describe the principle of operation of this model, the ratio of the emerging voltage and deformation on each section of the unit is applied according to the formula (3):

$$p_1\ddot{\sigma} + p_2\dot{\sigma} + p_3\sigma = q_1\ddot{\varepsilon} + q_2\dot{\varepsilon} + q_3\varepsilon \qquad (3)$$

Where *p* and *q* are the coefficients, depending on the method of connecting the elements in the model.

At the same time, there are no works showing the necessary requirements for the VES basic properties, which ensure the best efficiency of their use as viscoelastic spacer fluids (hereinafter - VESF).

At the same time, it should be borne in mind that the VESF is pumped into the casing pipes, and then passes into the annulus prior to the cement slurries, using cement pumpers. However, the prepared highly viscous VES with good displacing properties may not be “captured” for pumping even by the piston or plunger pumps. The presence of a highly viscous pill, moving in the pipes and annulus, can lead to an increase of pressure on the pumps or well layers, provoking the absorption of the process fluids or hydraulic fracturing. Obviously, the permissible values of the VES rheological properties should be evaluated or the time of the structure strength development should be determined.

Research methods and used materials

The main requirements for the VES, used as the VESF, are as follows: the strength and uniformity of the structure, minimum water trapping, an ability to fill in the annulus, retention of the cement slurry column, prevention of its cross flow with the VES, restoration of the main properties after deformation.

After analyzing the existing VES compositions, the following ingredients have been used for carrying out the research:

- sodium dichromate and aluminum sulfate as suppliers of cations;
- PAA of the following types: Flodrill Pam 1040 and Flodrill TS 705in the role of a polymer.

Sodium dichromate represents non-volatile crystals from light orange to dark red color, well-soluble in water and polar solvents. This product is a strong oxidizing agent, with a chemical formula $Na_2Cr_2O_7$. The chromium cation has a rate of oxidation of +6.

Aluminum sulfate represents a complex inorganic compound of aluminum salts and sulfuric acid, which can form crystalline hydrates with the different water content and has a chemical formula $Al_2(SO_4)_3$. The aluminum cation has a rate of oxidation of +3.

Flodrill TS 705 is sodium acrylate, a colorless powder used to control the drainage and drilling solutions, as well as to protect the sensitive dispersed systems from damage. It reduces the filtration of solutions, and is applicable at high pressure and temperatures.

Flodrill PAM 1040 is a partially hydrolyzed PAA, used as a drilling mud thickener, as well as a clay inhibitor.

The VES readiness has been evaluated by the elastic characteristic, obtained, using the conical indenter plastometer [15]. With the known weight of the cone and the measured area of its contact with the VES during immersion, the resistance of the cone is calculated, which indirectly characterizes the viscous properties of the system.

The rheological properties of the obtained VES have been studied with the help of a high-precision HAAKE MARS III rheometer, using the “plane-to-plane” method, which makes it possible to measure various types of fluids for compiling the rheological characteristics, especially for the viscous systems. This equipment is a hardware-software complex, consisting of a measuring device (a rotational viscometer) with a digital interface and a personal computer, equipped with the software for controlling the measuring device and processing the experimental data. Also, the NAAKE MARS III unit has an additional RheoWin option for measuring samples in the axial direction (an impact in the vertical direction by pressing or stretching the sample, with fixing the position of the probe, applied stresses and forces [16, 17]). Based on the obtained data, it is possible to determine the type of fluid, rheological characteristics, dependence on the tangential, normal or temperature effects upon the system. This rheometer uses the 3 types of tests: shear test, oscillator test and creep test. The first test determines the relationship between the shear stress and shear rate. The oscillation test is one of the most effective methods for studying the VES. The other tests, conducted on this device, make it possible to characterize the elasticity of the systems under study. The creep test is very suitable for the study of VES.

To study the other VES properties, the standard instruments and original units have been used.

Results of the VES experimental studies

Evaluation of the VES strength. The effect of crosslinkers, the polyvalent metals, on the VES strength characteristics is shown in Table1.

Table 1. Effect of the crosslinkers on the rate of gain of the VES viscoelastic properties

Time, min	Resistance to the immersion of the cone, when using the crosslinkers, Pa	
	$Al_2(SO_4)_3$	$Na_2Cr_2O_7$
0	30.4	32.1
2	38.4	43.5
4	42.8	51.2
6	51.2	61.2
12	61.6	75.3
18	75.3	85.3
24	78.9	90.1

From Table. 2 it is seen that the fastest rate of gain of the viscoelastic characteristics is observed for sodium dichromate. This is due to a high degree of oxidation of the polyvalent metal. Having donated an electron of the outer layer to oxygen, thereby becoming a positively charged ion with a rate of oxidation of 6+, chromium, when interacting with the partially hydrolyzed polyacrylamide, forms an ionic bond with the polymer macromolecules (Fig. 4), which has stronger strength characteristics than, for example, when using the reagents with an aluminum cation, whose oxidation rate is 3+.

However, a high oxidation rate of the metal cation does not always have a positive effect on the sedimentation and aggregative stability of the system. At a polymer concentration of more than 7–8%, PAA has coagulated and precipitated in the form of polymer beads.

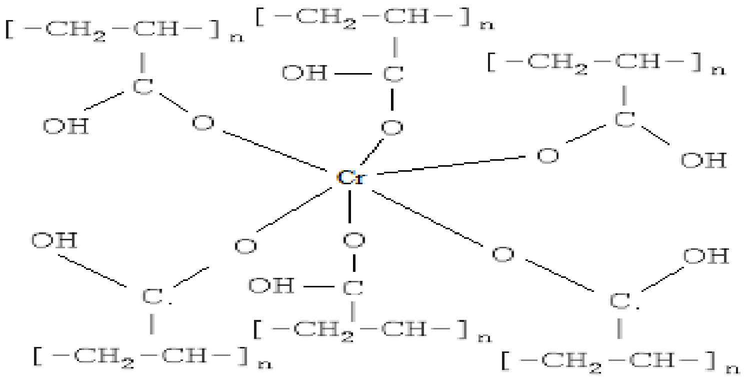


Figure 4. Structural formula of the hydrolyzed PAA with chromium dichromate

The experiments carried out have shown that the best results have been obtained when using Flodrill PAM 1040 as a structure forming agent, sodium dichromate $Na_2Cr_2O_7$ as a crosslinker. The VES included:

- Flodrill PAM 1040 with a constant concentration of 4%;
- sodium dichromate with the concentrations (0.25–4%);
- process water 150 ml.

Evaluation of the VES rheological properties

The VES rheological characteristics have been studied at the concentrations of $Na_2Cr_2O_7$ and PAA in the ratios of 1:1; 3:4; 1:2; 1:4; 1:6; 1:8; 1:16 and a temperature of 25°C. The shear rates have corresponded to the flow of these fluids in the casing pipes (500 c^{-1}), and in the well annulus (227 c^{-1}). The following results are shown in Fig. 5–7.

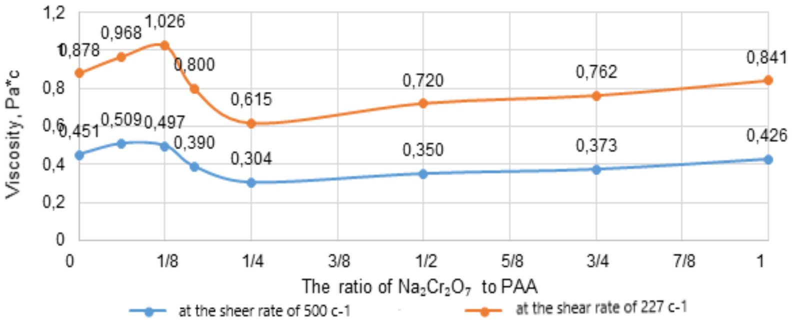


Figure 5. Effect of $Na_2Cr_2O_7$ concentration on the VES viscosity

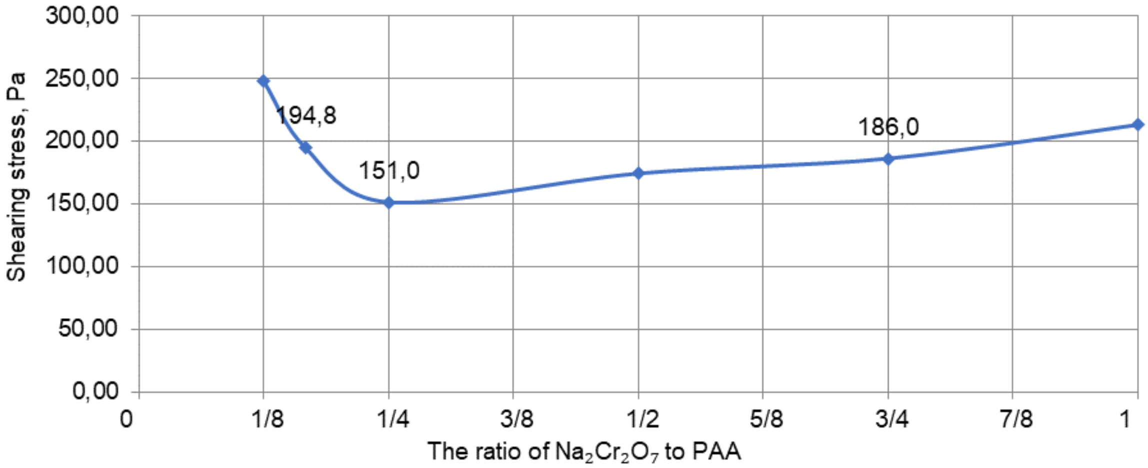


Figure 6. Effect of $Na_2Cr_2O_7$ on the flushing fluid stresses in the annulus at τ = 500 c^{-1}

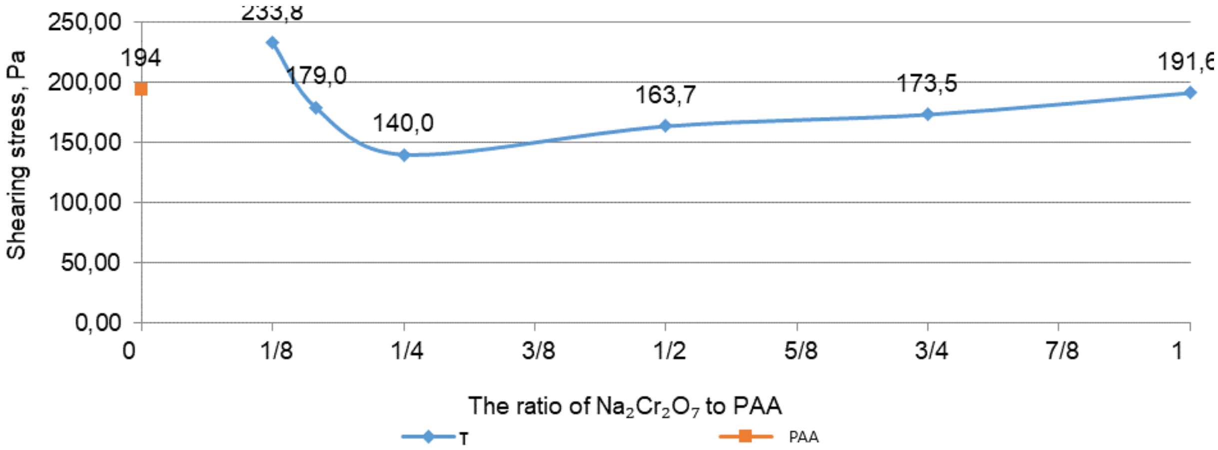


Figure 7— Effect of $Na_2Cr_2O_7$ on the flushing fluid stresses in the annulus at τ = 227 c^{-1}

The experimental results presented in Figs. 5–7 have shown that at the ratio of $Na_2Cr_2O_7$:PAA = 1:8, the viscosity of the flushing fluid is more optimal [5]. Perhaps this is due to the straightening of the network structure of the polymer macromolecules with an increase in the polymer ionization strength. When a polyvalent metal is added to the system, the following polymers are formed - polyelectrolytes (Fig. 8).

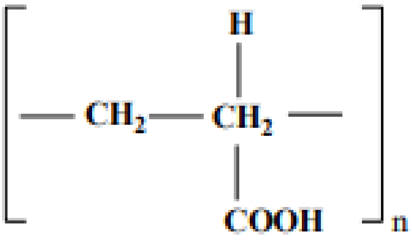
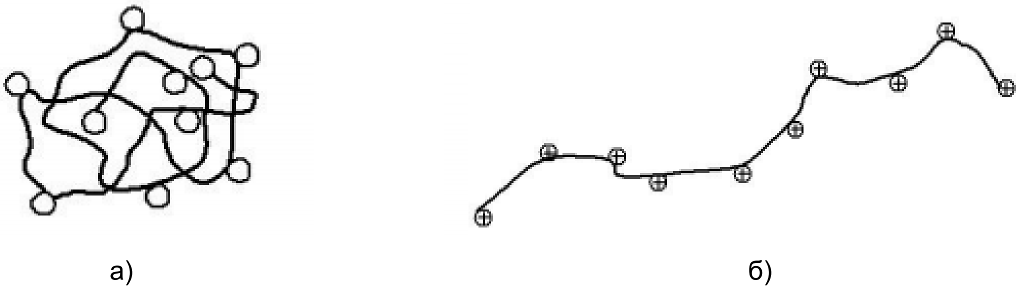


Figure 8. Structural form of polymeric (polyacrylic) polyelectrolyte

In the range of ratios 0–1/8, the concentration of chromium cations is low, and the emerging electrostatic forces of repulsion of the polymer macromolecules are minimal and insufficient for unrolling the polymer chain (Fig. 9a).

With an increase in the concentration of metal cations in the range of 1/8–1/4, the degree of ionization of the obtained polymers is much higher than that of the initial polyacids; therefore, the electrostatic repulsion force is higher. With the appropriate electrostatic repulsion forces, this leads to the unfolding of the molecular chains and to a strong increase in the size of coils (Fig. 9b). In this position, the friction between the polymer coils is less than in the compressed position of the chain, therefore, the viscosity is lower.



а) б)

Figure 9. Structure of the polyelectrolyte macromolecules in the non-ionized (a) and ionized (b) states

At a concentration of sodium dichromate in the range of 1/4–1, the unfolded polymer chains of the polymer begin to completely transform into the elongated configurations. In this case, the degree of ionization increases, and the influence of electrostatic forces increases. The formed chains increase in size, and a secondary electroviscous effect takes place due to the electrostatic repulsion forces [18].

Since the degree of wellbore cleaning and mud displacement depends on the ratio of viscosities of the contacting fluids, according to test results, the optimal ratio of the concentration of sodium dichromate and PAA (Flodrill PAM 1040) is in the range of 1/16–1/8.

The study of the VES carrying ability

The 3 types of flushing fluids have been compared:

1. Flushing fluid No. 1, based on PAA (Flodrill) 4%, sodium dichromate 0.5% and process water.
2. Flushing fluid No. 2, prepared on the basis of dry spacer powder Azimut BKh with the reinforcing filler VSM-II-6.
3. Flushing fluid No. 3, based on process water with the cotton filler.

Portland cement (hereinafter referred to as PC) I-G-SS-1, with a water-cement ratio of 0.5, has been used as the cement mixture.

To evaluate a carrying ability of the flushing fluids, the equipment has been used, shown in Fig. 10. The flushing fluids to be tested have been poured into the upper perforated glass, on the top of which the cement slurry has been poured. After 8 hours of testing, the flushing fluid, based on process water with the cotton filler could not retain the cement slurry, while the other flushing fluids have prevented mixing of the contacting fluids quite well. However, while waiting on the cement to harden (hereinafter referred to as the WOC), a channeling overflow of the cement slurry through the flushing fluid No. 2 has occurred.

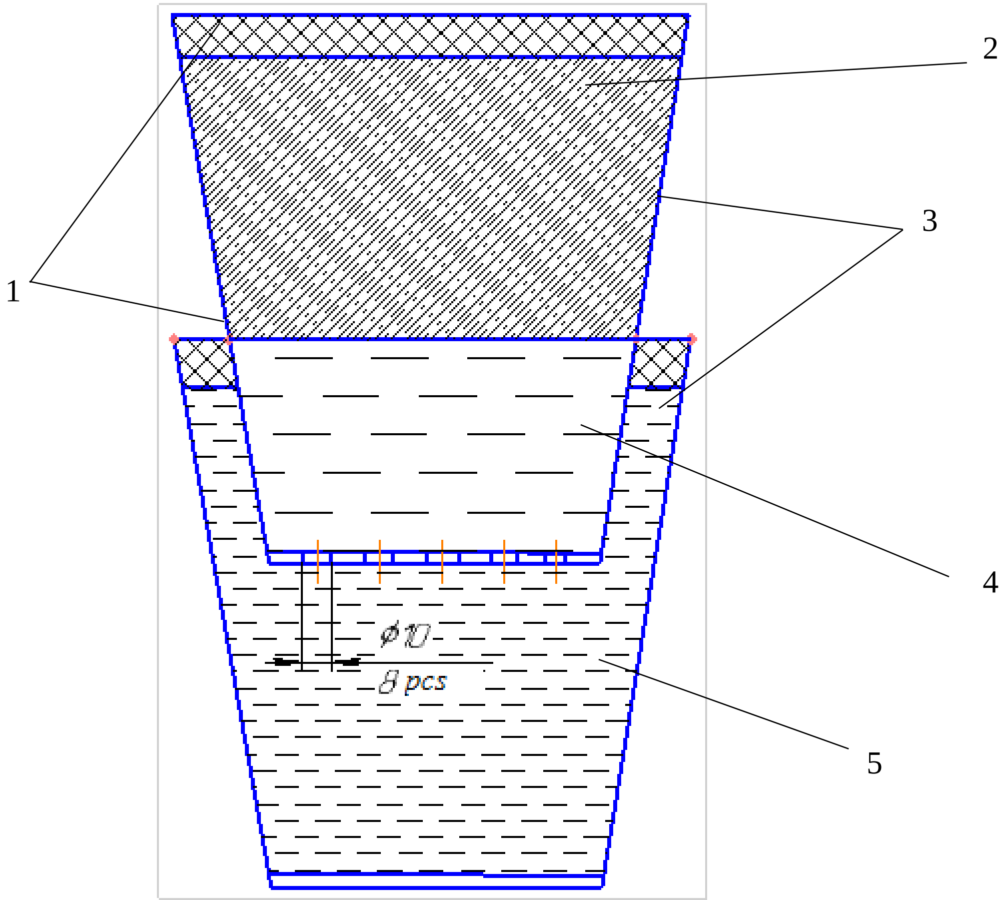


Figure 10. Scheme of the device for assessing a carrying ability of the flushing fluid

1 - rubber gaskets; 2 - cement slurry; 3 - glasses; 4 –flushing fluid; 5 - process water

Study of the processes of displacing the flushing fluid of the process liquids. The experiments have been carried out on the unit, described in [19], which has been a model of an inclined well section (30°) with a casing in it. A clay solution with a density of 1100 kg/m³ has been used as a displacing fluid. At the same time, the criteria for the similarity of the fluid in the model and in the real well have been observed.

For the experiments, the 3 viscoelastic flushing fluids have bee used:

-Azimut BH VES;

- 4% PAA (Flodrill PAM 1040) without a crosslinker;

- 4% PAA (Flodrill PAM 1040) with a crosslinker.

TheresultsoftheexperimentsarepresentedinTable2.

Table 2. Results of the study of a displacement ability of the flushing fluids

Fluid consumption, l/s	Flushing fluid	Volume of the resulting mixture, l	Displacement ratio	Mixing ratio
1.5	Azimuth BH	6.3	0.697	0.303
	Flodrill Pam 1040	5.7	0.796	0.204
	Flodrill Pam 1040 with a crosslinker	4.9	0.884	0.116

When using a unit with a cavern model [20], it has been shown that the viscoelastic flushing fluid has moved throughout the entire volume of the cavern, completely filling the well annular. In this case, no mixing of the fluids and no stagnant zones in the cavern have been observed. The displacement of the two fluids has been the most complete, compared with the replacement of the same fluids, but without the VESF.

Evaluation of the effect of the polymer film upon the adhesion of the cement stone to the casing string

PC I-G-SS-1 with a water-cement ratio of 0.5 has been used as a cement slurry. The cleansing fluid has been represented by a polymer clay solution, including (bentonite - 6%, bioxane - 0.2%, CMC - 0.5%, marble chips - 10%, Na_2CO_3 - 2%, KCl - 5%, FCLS - 1.5%, process water). The flushing fluid has included Flodrill PAM 1040 4%, sodium dichromate 0.5% and process water. The contact strength of the cement stone with the metal has been estimated by the force of displacing the cement stone from the metal rings, which were alternately filled with the cleansing fluid (exposure 10 min), flushing fluid (exposure 1 min), cement slurry (WOC 2–14 days). Besides, the tests have been carried out without the use of the flushing fluid, and using a diluted cement slurry with a density of 1200 kg/m³ as a flushing fluid. The results of the experiment are shown in Fig. 11.

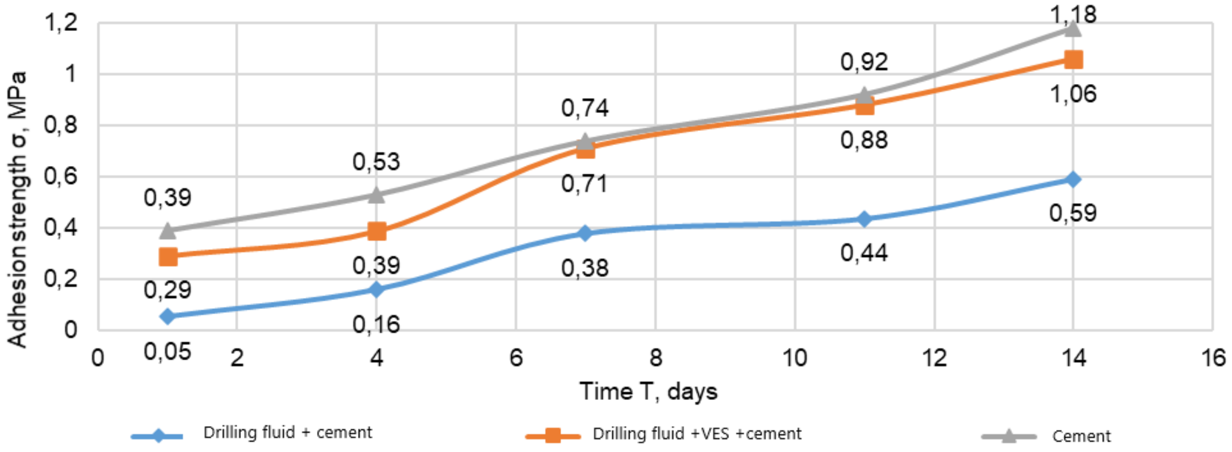


Figure 11. Effect of the flushing fluids upon the adhesion of the cement stone to metal

The conducted experiments have shown that the formed polymer-clay film increases the adhesion strength of the cement stone with the borehole wall by approximately 70%. This is explained by the fact that the formed film acts as an intermediate zone in the “cement stone - filter cake – rock” system. As the cement slurry hydrates and hardens, the polymer, interacting with the cement hydration products, can form new crystalline hydrates, which have a greater lyophilicity to form strong bonds with the cement stone and, as a result, increase the strength and adhesion of the system. However, the polymer film still degrades the quality of contact of the cement stone with the casing, so it is better to remove it. To do this, it is advisable to use complex flushing fluids, including the VES, for better displacement of the drilling fluid from the caverns, while the second cleansing portion of the flushing fluid is based on a polymer destructor, and the third portion can be used to strengthen the remaining part of the clay cake on the well walls [21].

Conclusion

1. When choosing a polyvalent cation as a “crosslinker” for the viscoelastic systems, it is necessary to use the additives with the highest rate of oxidation, for example, Cr^{+6} or Al^{+3}.
2. The cations with a higher rate of metal oxidation increase the rate of the VES strength gain, compared with the use of the metal cations with a lower rate of oxidation.
3. An increase in the concentration of the chromium cation increases the viscosity of the system due to an increase in the forces of electrostatic repulsion, and unrolls a polymer network structure in the chain. The maximum viscosity of the VES is observed at the concentration ratio of sodium dichromate and PAA (Flodrill PAM 1040) 1/16–/1/8.
4. The VESF demonstrate a better carrying ability, compared with the other types of the flushing fluids, which eliminates the flow of cement slurry down in the well annulus after the completion of the cementing process.
5. It has been experimentally shown that PAA and sodium dichromate-based VESF provides the best degree of wellbore cleansing in the cavern zones under the laminar flow regime.
6. The use of the VESF increased the contact strength of the cement stone with metal by 70–80% in the presence of a polymer-clay film due to the formation of the polymer crystalline hemihydrates at the contact point of the cement slurry and polymer-clay cake.

3. To minimize a negative effect of the polymer films on the adhesion of the cement stone to the casing strings, it is advisable to pump a portion of the fluid, containing a polymer destructor after a portion of the VESF.

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ҰҢҒЫМАЛАРДЫҢ ҚҰРЫЛЫСЫ КЕЗІНДЕГІ ТҰТҚЫР СЕРПІМДІ ЖҮЙЕЛЕР

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Ұңғымаларды бекітудің қажетті сапасын қамтамасыз ететін маңызды факторлардың бірі тиімді буферлік сұйықтықтарды қолдану болып табылады, олардың арасыннан цементтеу кезінде жуу сұйықтығының жақсы ығысуын қамтамасыз ететін тұтқыр серпімді жүйелерді бөліп көрсету керек.

Мақалада поливалентті металл катиондарымен тігілген полиакриламидті қолдану кезінде тұтқыр серпімді жүйелерді полимерлеу механизмі және ұңғымаларды бекіту кезінде осы жүйелерді қолдану перспективалары қарастырылған. Тұтқыр серпімді жүйелердің ағымының модельдері және олардың арасындағы айырмашылықтар, тұтқыр серпімді жүйелерінде қалыпты кернеулердің болуына байланысты көрсетілген. Тұтқыр серпімді жүйелердің компоненттік құрамының және олардың негізгі қасиеттерінің негіздемесі берілген, бұл жүйелердің буферлік сұйықтар ретінде тиімділігін қамтамасыз етеді, сонымен қатар зерттеуге арналған құрылғылар сипатталған.

Поливаленттi катионды тұтқыр серпiмдi жүйелердiң «тiгiндегiш» ретiнде таңдаған кезде берiктiк сипаттамалары жиынтығының жылдамдығын арттыратын ең жоғары тотығу дәрежесi бар қоспаларды қолдану қажет екендiгi эксперименталды түрде расталды. Құрамдастардың ең ұтымды қатынасы эксперименталды түрде негiзделген және цементтеу процесi аяқталғаннан кейiн ұңғымалардың құбыр кеңiстiгiнде цемент ерiтiндiсiнiң төмен түсуiн болдырмайтын буферлiк сұйықтықтардың басқа түрлерiмен салыстырғанда тұтқыр серпiмдi буферлiк сұйықтықтың жақсы ұстау қабiлетi дәлелденген.

Түпнұсқа қондырғыларда ламинарлық ағыс режимi кезiнде каверна аймақтарында ұңғыма оқпанын тазартудың ең жақсы дәрежесi дәлелденген. Тұтқыр серпiмдi жүйелерден полимерлi пленкалардың цемент тасының шегендеу бағанына бекiтуiнiң терiс әсерiн азайту үшiн тұтқыр серпiмдi буферлiк сұйықтықтың бiр бөлiгiнен кейiн құрамында полимер деструкторы бар сұйықтықтың бiр бөлiгiн айдау ұсынылады.

Негiзгi сөздер: буферлiк сұйықтық, құбыр сыртындағы кеңiстiк, тұтқыр серiпмдi жүйелер, полимер, реология.

VISCOELASTIC SYSTEMS FOR WELL CONSTRUCTION

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One of the most important factors that ensure the required quality of well casing is the use of effective flushing fluids, among which viscoelastic systems should be singled out, providing the best displacement of drilling fluid during the cementing process.

The article considers the mechanism of polymerization of the viscoelastic systems when using polyacrylamide, cross-linked with the polyvalent metal cations, and the prospects for using these systems for well casing. Models of the flow of the viscoelastic systems and their differences due to the presence of normal stresses in the viscoelastic systems are shown. The justification of the component composition of the viscoelastic systems and their main properties, which ensure the effectiveness of these systems as the flushing fluids, is provided, and the research devices are described.

It has been experimentally confirmed that it is necessary to use additives with the highest degree of oxidation, which increase the rate of strength gain when choosing a polyvalent cation as a “crosslinker” for the viscoelastic systems. The most rational ratios of components are experimentally substantiated, and the best holding capacity of the viscoelastic flushing fluid is proved in comparison with the other types of spacers, which excludes the flow of cement slurry down in the well annulus after the completion of the cementing process.

The best degree of cleaning the wellbore in the zones of caverns with a laminar flow regime has been proven on the original installations. To minimize the negative effect of polymer films from the viscoelastic systems on the adhesion of cement stone to *casing strings, it is recommended to pump a portion of a fluid, containing a polymer destructor, after a portion of a viscoelastic flushing fluid.*

Key words: flushing fluid, annulus, viscoelastic systems, polymer, rheology.

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