

# РОЗРОБКА РОДОВИЩ КОРИСНИХ КОПАЛИН

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## ELABORATION OF REINFORCED CEMENT MATERIAL FOR CEMENTING OF DEVIATED WELLS

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## РОЗРОБКА РЕЦЕПТУРИ АРМОВАНОГО ТАМПОНАЖНОГО МАТЕРІАЛУ ДЛЯ ЦЕМЕНТУВАННЯ ПОХИЛО-СКЕРОВАНИХ ДЛЯНОК СВЕРДЛОВИН

**Purpose.** To improve mechanical properties of cement stone and rheological properties of cement slurries, which are used to cement deviated wells by means of development of reinforced cement slurry mixtures.

**Methodology.** Computational modeling of the cement stone sheathing of the well, which operates under well conditions, was performed. On the basis of laboratory studies of the properties of cement slurry and stone with the various types of reinforcing additives, the optimum content of the reinforcing additive was established based on the features of the work of the material in the deviated section of the well.

**Findings.** Analysis of literature sources as well as conducted calculations has shown that at the stage of construction of deviated section of the well, there is a risk of cracks appearing in the cement stone behind the casing string. It was established that the cement materials used at the present time cannot withstand the stresses that occur in the cement stone during the drilling of the deviated section of a well. It has been found that the use of a synthetic reinforcing additive improves the strength and fracture toughness of a cement material by 2 and 3 times, respectively. It has been proved that the use of a combination of calcium chloride additives and a reinforcing agent during the preparation of cement slurry allows reducing the Young's modulus of the cement stone, which is the basis for improving its deformability. The addition of calcium chloride and fiber to the cement slurry increases its sedimentation resistance, which greatly contributes to the prevention of the cracks in the annulus of directional wells and increases the homogeneity of cement material.

**Originality.** By means of laboratory tests the value of Young's modulus for cement stone was detailed, which is less than 54–65 % compared with the value of the same indicator for traditional cement stone without the reinforce additive component in it, which explains improvement of deformation characteristics. A new blend composition of cement slurry has been developed that makes cement stone to provide containment of annular workspace of deviated part of a well while conducting different types of technical operations in it.

**Practical value.** Use of a new cement stone will allow increasing the period of accident-free operation of deviated part of a well and improving containment of annular workspace.

**Keywords:** *deviated well, cement stone, sedimentation stability, reinforce additive*

**Introduction.** Well casing, regardless of its purpose, should ensure reliable and safe exploration of a well throughout its life. The problem of improving well cementing quality remains relevant because of stressful conditions of work of cement ring in a well due to carrying out a wide range of technological operations in it during its construction and exploration [1]. Particularly acute, this problem

affects directional sections of wells. First of all, it is connected with application of excessive static and dynamic loads on the casing because of change of well trajectory of the drill string.

What is more, additional requirements are indicated for sedimentation stability of cement slurry, because the part of the casing string is positioned at an angle (and sometimes horizontally) to the vertical component of the well, significantly reducing the thickness of the layer

of cement in the annular space. Such conditions of cement material placement accelerate the processes of sedimentation that can lead to the formation of channeling in the well [2].

**Unsolved aspects of the problem.** The analysis of the literature allowed concluding that one the reasons for intercase pressure and annular leakage are unsatisfactory deformation characteristics of cement plugs and insufficient tightness of its contact surfaces around it. There is also the need in developing cement material which is able to resist the spread of cracks in it due to the constant dynamic loads presence at the contact of a casing string with a drill one.

**Analysis of the recent research.** Most authors such as Kharitonov [3], Beliaiev, Kliuksov think that the main reason for cracks in the cement stone is the occurrence of local and general stress, whose value exceeds the elastic modulus and yield strength of the material in tension. Assessing methods for fracture strength are divided into three groups: direct assessment of fracture strength, indirect assessment and evaluation based on modeling of material structure and methods of fracture mechanics by which is possible to obtain quantitative and qualitative characteristics of crack strength.

Many local and foreign scientists, such as Vasylenko [4], Pervushin [5] and Bulatov, considered methods of improving the composition of cement materials to improve the quality separation of productive horizons.

The author [6] has developed a composite material of oil, which includes artificial mineral fiber composition of silica and aluminosilicate compound of glassy structure (fiber) in an amount of 0.5 %, which enhances impact resistance of stone and its ability to resist dynamic load in 2.5–6.2 times. It helps to maintain stone bend strength at 28 days and reduce its Young's modulus by 35 %. The disadvantage of using glass fibers as reinforcing impurities is insufficient loosening of fibers, which leads to the formation of clots in the fiber cement stones and, consequently, its properties become anisotropic. Moreover, fiberglass tends to decompose in the structure of cement compromising its properties [7].

**Objectives.** The aim of the research was to improve strength and rheological properties of cement slurries that are used for cementing of deviated wells. Achieving of this goal will increase tightness of annular space of horizontal wells with horizontal deviation and reduce the cost of their repair and maintenance.

**Presentation of the research.** Assessing the state of cement stone in the annular space of the well, while deepening deviated wells, was made in several of the most common well constructions and technological parameters of drilling at PJSC “NJSC” Chornomornaftogaz”. For these conditions (Table 1) the contact surface dis-

placement of the “cement stone – casing” system was defined in case of application of external and internal pressures on the wall of the casing (Fig. 1).

The following parameters were taken into account while calculations: tensile stress as a result of the hydrostatic pressure of the column of drilling fluid ( $P_B$ ), the load created by the interaction of the bottom of the drill string at contact with the inner surface of the casing, compressive load generated by cement ring in annular space that was expressed in terms of contact pressure ( $P_K$ ) in the “cement stone – casing pipe” system. The interaction result of such loads is a stress concentration at the point of its application. In order to assess the integrity of the cement rings within the study area the actual movement of the contact surface has been defined with the help of a computer model of well casing stress (Fig. 2). Modeling was performed using the software Solid Works.

Boundary conditions for study models:

1. Material of casing model is considered as an isotropic linear elastic body, whose strength is measured by Mises criterion.

2. Kinematics model provides a rigid fixation of the restrictive model planes and the free movement of other surfaces.

3. The force applied to the inner surface of the model is normally and evenly distributed over a given area. The direction and magnitude of force remain unchanged.

In order to increase the strength and fracture resistance of cement material it was decided to include reinforcement additives into its mixture. To select the type of additives, a number of laboratory experiments with a range of synthetic and mineral fiber type were conducted. Among synthetic additives, such materials were tested as fiber polypropylene (PPF), polyamide (PAF) and carbon fiber. Among the mineral admixtures, wollastonite fibers, basalt and asbestos were tested. In the experiment we used statistical data according to the criterion of “three sigma”. This method of mathematical statistics eliminates errors (abnormal values), which may be caused by imperfect methods of measurement. The procedure for exclusion of abnormal results was carried out so that all options of considered samples were obtained under the same conditions. The order of statistical analysis is as follows: the arithmetic mean of the parameter, standard deviation, coefficient of variation, error standard deviation and confidence interval (given confidence probability 0.95) are determined. The next step was the calculation of confidence intervals and comparing them with the value of the triple size of obtained deviation.

The results of laboratory research studies of the deformation characteristics of the cement stone (Fig. 3) indicate that the stone with an admixture of chrysotile-asbes-

Table 1

Output data for calculation of outside surface displacement of casing pipe model (Fig. 1)

№	Parameter	Value	№	Parameter	Value
1	Outside casing diameter, m	0.2445	4	Width of contact surface, m	0.005–0.007
2	Wall thickness, m	0.01	5	Module of elasticity, Паа	$2.1 \cdot 10^{11}$
3	Length of the model, m	14–15	6	Poisson ratio of the steel	0.25

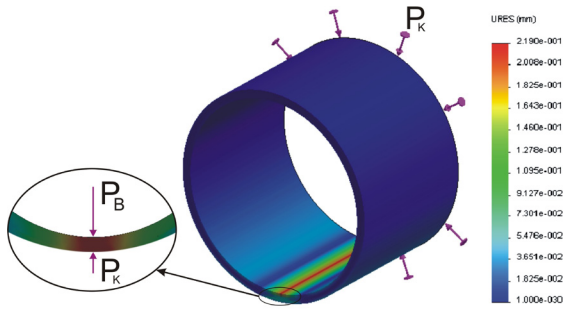


Fig. 1. Chart of displacement of casing surface model while drilling out a cement plug in a casing pipe

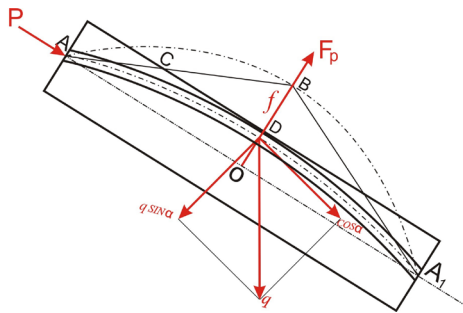


Fig. 2. Chart of interaction between a drilling pipe and wall of a casing pipe while drilling out a cement plug in a casing pipe

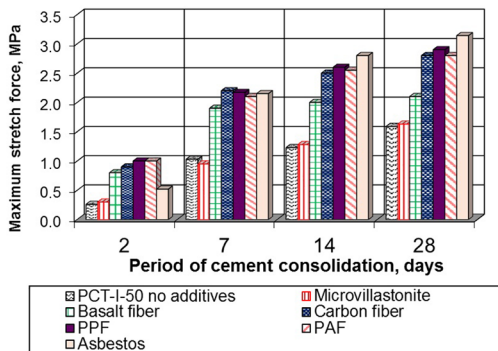


Fig. 3. Results of investigation of stretch-strength of reinforced cement stone

tos at the age of 28 days has a 10 % greater tensile strength compared with the impurities of PPF and PAF. This is due to the better integration of chrysotile fibrils in the matrix of the binding material, although the use of PPF also increases strength of the basic cement material based on cement with PCT-I-50. This indicates good adhesion of PPF fibers with a matrix in the binding material.

At the same time, laboratory studies of stroke resistance of the reinforced cement stone with fibers PPF and PAF (RCS) showed that the experimental samples have practically the same energy intensity in crushing. This property of a material with impurities of PPF and PAF may be explained by preservation of mechanical elasticity, regardless of the environment and the term of application.

Regarding the usage of asbestos fibers as a reinforcing impurity, in connection with its chemical integration

into the matrix of the binding material, it eventually acquires the same mechanical properties as the cement stone, so that, it becomes firm, but fragile. Since it is impossible to eliminate the presence of dynamic loads on the borehole during the construction of its incline part (especially in the perforation zone of the casing), the fragility of the cement material is an undesirable indicator from the position of maintaining the integrity of the borehole.

Taking into account the fact that the cost of polyamide fibers is twice as high as the cost of polypropylene, and the deformation-strength characteristics of the cement stone with the additive of these impurities are almost identical, further research was carried out using polypropylene fibers as a material for RCS.

Thus, for further research, an admixture of PPF, which has twice as good as that with asbestos, was chosen, and three times as good as cement with PCT-I-50 absorption energy, which is extremely dangerous from the point of view of maintaining the tightness of the recessed well space, especially while constructing its lateral borehole.

Polypropylene fiber is a synthetic fiber, which is made by extrusion of polypropylene (thermoplastic polymer of propylene). It is chemically cement-inert relating to hydration products.

Taking into account the fact that the cement stone in the annular space both at the early hardening stage and in the process of well construction and operation carries out huge loads, it is recommended to introduce a hardening accelerator – Calcium chloride ( $\text{CaCl}_2$ ) in order to obtain stable solution and a strong rock in the initial period. In addition, this impurity will improve the rheological properties of the solution.

Experiment planning was performed using the Latin squares method in order to determine the influence of each of the factors on the result of the study while simultaneously changing all other factors. This method also ensures an even coverage of the experiments of the whole area of the change of influential factors with a minimum number of experiments. Levels of factors vary so as to highlight the dependence of the outcome on any factor in neutralizing the influence of the remaining factors.

In order to assess the deformation ability of the RCS of the selected composition, its elastic characteristics, in particular Young's modulus, were determined. For this purpose, a study was carried out to determine the maximum deformations of a cemented sample of rectangular shape (40x40x100 mm) with its three-point bending and the corresponding applied loads.

As it was indicated earlier, if the cement solution is planned to be placed in the lateral well interval, then the index of its sedimentation stability has special requirements, which were partially formulated in the scientific studies of Bulatov A. I.

To assess the ability of the cement solution in reservoir conditions to maintain the uniformity of the structure, such indicator as the coefficient of sedimentation stability is adopted. It is estimated by the level of density decrease of the cement solution during stuttering in the annular space because of sedimentation.

$$K_{SED} = \frac{\Delta\rho}{\rho_0} 100\%,$$

where  $\Delta\rho$  is the difference between the densities of the lower and upper parts of the cement stone after its hardening in reservoir conditions;  $\rho_0$  is the initial density of the cement slurry.

In accordance with the conditions of the construction of lateral wells, the reduction of the density of the pillar of the cement solution in the upper part of the operating shelf by 1–1.5 % can lead to loss of hydrostatic balance in the “well-formation” system and cause the occurrence of complications. In this regard, the limit value of the coefficient [ $K_{SED}$ ] is taken within the limits of 1–1.5 %. The established restriction will allow avoiding depression on a formation and to form a dense tampon stone.

Studies on sedimentation stability of the reinforced cement mixture were conducted to verify its compliance with a specific criterion. This quality index was determined by pouring the cement solution into a special form, which was placed in an autoclave of the CC-3 consistometer for 2 days in an upright position. After that, the cement stone was removed from the mold, divided into two parts, and the density of the separate upper and lower parts was determined. All samples were prepared at WCR = 0.5 (water/cement ratio) and stored in conventional ( $P = 101.3$  kPa,  $T = 20$  °C) and formation ( $P_{FORM} = 20$ – $22$  MPa,  $T_{FORM} = 50$ – $55$  °C) conditions.

The change in the density of the cement stone was determined at the age of 2 days, because after the end of the period of endurance, the transfer of mass in a hardening solution ceases, the sedimentation processes stop.

### 1. Investigation of the well casing model.

The results of the calculations showed that increase in the internal pressure in the casing, due to its interaction with the drill column, for all the models under study is estimated within a range from 2 to 5 MPa. Such circumstances lead to deformation of the contact surface, which exceeds the critical value by 1.5–2 times.

Thus, during the drilling of the lateral well section, there is a gap between the contact surface between the casing and the cement ring as a result of its irreversible deformation. This is due to the appearance of values of internal tensile loads in the zone of their contact, in which the value of the deformation of the cement material exceeds the maximum values of its plastic deformation.

### 2. Investigation of RCS deformation.

Experimental studies have established (Table 2) that the modulus of elasticity of RCS is 54–56 % less in comparison with the elastic modulus of the cement

stone with PCT-I-50 (with WCR = 0.5). Thus, the magnitude of the permissible deformations that can be taken into account by the clasp of stone prior to its destruction increases.

The analysis of the obtained results shows that the actual deformation of RCS is less than the permissible by 1.1–1.5 times, indicating the preservation of the impermeability of the contact surface of RCS during drilling of the lateral well section. When comparing the results obtained for the cement material on the basis of the cement brand PCT-I-50 without impurities, it was established that the displacement of the border of the “cementing stone – casing column” system for RCS has increased from 7 to 40 %. At the same time, the values of contact pressure also increases by 1.5–2 times, which will reduce stress in the contact area.

### 3. Investigation of sedimentation stability.

According to the results of laboratory studies (Fig. 4) it was established that the coefficient of  $K_{SED}$  is by 10–15 % higher during the setting of the cement solution in formation conditions rather than in normal conditions, which is explained by the increase in the velocity of mass transfer processes at high temperatures and pressures.

Studies have also determined that the minimum values for  $K_{SED}$  have cement materials that contain 2.5 %  $CaCl_2$  and 0.5–0.6 % PFF for both normal and formation conditions (Table 3).

This is explained by the fact that the fiber admixture contributes to the reduction of the intensity of mass transfer processes due to its “freezing” in a dispersed medium and the creation of a barrier for the dispersion phase in it. The impurity of  $CaCl_2$  reduces the duration of hydration of the trowel material, which reduces the

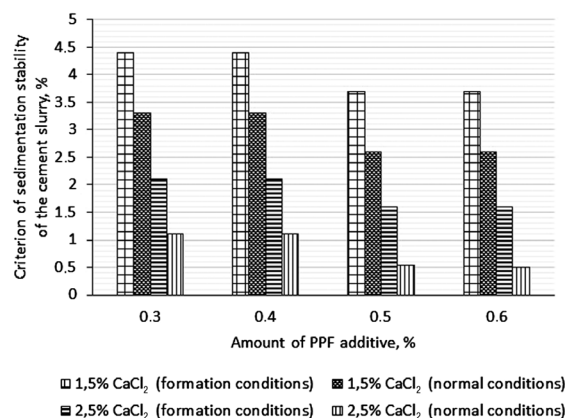


Fig. 4. The trend of the coefficient of sedimentation stability regarding the amount of PPF and  $CaCl_2$  additives in a cement slurry

Table 2

Deformation characteristics of cement stone

Period of cement consolidation	Young’s modulus, $\times 10^9$ Pa		Maximum load at the area of elastic strain, MPa	
	PCT-I-50 without additives	RCS	PCT-I-50 without additives	RCS
2 days	2.4–2.5	1.3–1.4	0.4	1.6
28 days	3.6–3.8	2.1–2.2	1.6	3.9

Table 3

Results of cement slurry sedimentation index investigation which is made of PCT-I-50 and RCS (Fig. 4)

№	Amount of additive, %		Sedimentation index $K_{SED}$ , %		№	Amount of additive, %		Sedimentation index $K_{SED}$ , %	
	PPF	CaCl <sub>2</sub>	Normal conditions	Formation conditions		PPF	CaCl <sub>2</sub>	Normal conditions	Formation conditions
1	0	0	3.78	4.32	8	0.5	2	1.62	2.70
2	0.3	1.5	3.24	4.32	9	0.6		1.62	2.70
3	0.4		3.24	3.78	10	0.3	2.5	1.08	2.16
4	0.5		2.70	3.78	11	0.4		1.08	2.16
5	0.6		2.70	3.78	12	0.5		0.54	1.62
6	0.3	2	2.16	3.24	13	0.6		0.54	1.62
7	0.4		2.16	3.24					

time for mass transfer and reduces the duration of the formation of the stone.

#### Conclusions.

Thus, as a result of the theoretical and experimental research carried out, the following conclusions are made:

1. While drilling the lateral well section, there is a rupture of the contact surface between the casing and the cement ring at the lateral zone of the well due to the irreversible deformation of the cement. This is due to the appearance of internal tensile loads. The action of loads causes an excess of the permissible value of the plastic deformation of the trowel stone. As a result, this creates a gap between the contact surfaces, which causes loss of tightness and creates conditions for the migration of the formation fluid in the annular space.

2. It is proved that the use of synthetic reinforcing impurity PPF allows increasing the durability and fracture strength of the material on the basis of cement grade PCT-I-50 by 2 and by 3 times, respectively, in comparison with the basic material.

3. It has been established that the use of a combination of impurities PFP and CaCl<sub>2</sub> during the preparation of cement slurry, in the amount of 0.5–0.6 and 2–2.5 %, respectively, reduces the Young's modulus of the cement material, which is the basis for improving its deformation ability.

The injection of the CaCl<sub>2</sub> and PPF in the above-mentioned cement admixture in the above mentioned amounts increases the sedimentation stability of the final cement material, which greatly prevents the formation of a fluid-conducting channel in the annular space of the lateral section of the well and increases the homogeneity of the material. These circumstances are critical for improving the quality of cementing of lateral wells.

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**Мета.** Удосконалити міцнісні властивості каменю та реологічні властивості тампонажних розчинів, котрі використовуються для кріплення похило-скерованих свердловин шляхом розробки рецептури армованого тампонажного матеріалу.

**Методика.** Виконано комп'ютерне моделювання оболонки тампонажного каменю, що працює у свердловинних умовах. На основі лабораторних досліджень властивостей тампонажного розчину та каменю з додаванням різного роду армуючих домішок встановлено оптимальний вміст армуючої домішки виходячи з особливостей роботи матеріалу в похило-скерованій свердловині.

**Результати.** Аналіз літературних джерел і проведені розрахунки показали, що на стадії будівництва похило-скерованої ділянки свердловини існує ризик виникнення тріщин у цементному камені за обсадною колоною. Встановлено, що тампонажні матеріали, які використовуються на даний час, не можуть протистояти напруженням, котрі виникають у цементному камені під час буріння похило-скерованої ділянки. Доведено, що використання синтетичної армуючої домішки дозволяє підвищити міцність і тріщиностійкість тампонажного матеріалу у 2 та 3 рази відповідно. Доведено, що використання комбі-

нації домішок хлористого кальцію та армуючої домішки під час приготування цементного розчину дозволяє зменшити модуль Юнга тампонажного матеріалу, що є основою покращення його деформаційної здатності. Додавання до тампонажного розчину домішок хлористого кальцію й фіброволокна збільшує седиментаційну стійкість кінцевого тампонажного матеріалу, що у значній мірі сприяє попередженню утворення в заколонному просторі похило-скерованої ділянки свердловини флюїдопровідних каналів і підвищує однорідність матеріалу.

**Наукова новизна.** Експериментальними дослідженнями уточнена величина модуля Юнга армованого тампонажного каменю, який на 54–56 % менший у порівнянні зі значенням цього показника для традиційного тампонажного каменю без армуючих домішок, що пояснює покращення його деформаційних характеристик. Розроблено новий компонентний склад тампонажного розчину, тампонажний камінь з якого забезпечує герметичність заколонного простору похило-скерованої ділянки свердловини під час виконання в ній різного роду технологічних операцій.

**Практична значимість.** Використання нового армованого тампонажного матеріалу дозволить подовжити безаварійний термін роботи ділянки набору кута свердловини й підвищити герметичність його заколонного простору.

**Ключові слова:** *похило-скерована свердловина, тампонажний камінь, седиментаційна стійкість, армуюча домішка*

**Цель.** Усовершенствовать прочностные свойства камня и реологические свойства тампонажных растворов, которые используются для крепления наклонно-направленных скважин путем разработки рецептуры армированного тампонажного материала.

**Методика.** Выполнено компьютерное моделирование оболочки тампонажного камня, которая работает в условиях скважины. На основании лабораторных исследований свойств тампонажного раствора и камня с добавлением разного рода армирующих добавок установлено оптимальное содержание армирующей добавки исходя из особенностей работы материала в наклонно-направленном участке скважины.

**Результаты.** Анализ литературных источников и проведенные расчеты показали, что на стадии стро-

ительства наклонно-направленного участка скважины существует риск возникновения трещин в цементном камне за обсадной колонной. Установлено, что тампонажные материалы, которые используются в настоящее время, не могут противостоять нагрузкам, что возникают в цементном камне во время бурения наклонно-направленного участка. Установлено, что использование синтетической армирующей добавки позволяет улучшить прочность и трещиностойкость тампонажного материала в 2 и 3 раза соответственно. Доказано, что использование комбинации добавок хлористого кальция и армирующей добавки во время приготовления цементного раствора позволяет уменьшить модуль Юнга тампонажного материала, что является основой улучшения его деформационной способности. Добавление в раствор добавок хлористого кальция и фиброволокна увеличивает седиментационную стойкость конечного тампонажного материала, что в значительной мере способствует предупреждению образования в затрубном пространстве наклонно-направленного участка скважины флюидопроводящих каналов и повышает однородность материала.

**Научная новизна.** Экспериментальными исследованиями детализировано значение модуля Юнга армированного тампонажного камня, который на 54–56 % меньше по сравнению с величиной этого показателя для традиционного тампонажного камня без армирующего компонента в его составе, что объясняет улучшение его деформационных характеристик. Разработан новый компонентный состав тампонажного раствора, тампонажний камінь из которого обеспечивает герметичность заколонного пространства наклонно-направленного участка скважины во время проведения в нем разного рода технологических операций.

**Практическая значимость.** Использование нового тампонажного материала позволит продлить безаварийный срок работы участка набора угла скважины и повысить герметичность его заколонного пространства.

**Ключевые слова:** *наклонно-направленная скважина, тампонажний камінь, седиментаційна стійкість, армирующая добавка*

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