IMPROVING THE CEMENTING OF OIL AND GAS WELLS PRODUCTION STRINGS WITH HYDROPHOBIC MATERIALS OF THE “RAMSINKS – 2” GROUP IN VARIOUS MINING AND GEOLOGICAL CONDITIONS

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ABSTRACT. Under laboratory conditions, samples of the “Silpan-P” cement slurries (the “Ramsinks – 2” group) have been tested to improve the quality of delineation of water and gas bearing strata by improving the technology of cementing production strings of oil and gas wells in the drilling department of “Ukrburgaz” (for intermediate and production casing), especially in the presence of closely located productive formations and aquifers with different coefficients of anomalies. The use of the “Silpan-P” hydrophobic plugging solution was proven to be reasonable. Physical, chemical, and mechanical properties of the “Silpan-P” plugging hydrophobic solution significantly improve the isolation of productive formations at the stages of well completion.

Key words: reservoir column, well, cement, hydrophobic solution, hydrophobic addendum

ПОДОБРЯВАНЕ НА ЦИМЕНТИРАНЕТО НА ПРОИЗВОДСТВЕНИТЕ КОЛОНИ В НЕФТНИ И ГАЗОВИ СОНДАЖИ С ХИДРОФОБНИ МАТЕРИАЛИ ОТ ГРУПАТА „RAMSINKS – 2“ ПРИ РАЗЛИЧНИ МИННИ И ГЕОЛОЖКИ УСЛОВИЯ

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РЕЗЮМЕ: Проби от течен циментов разтвор «Силпан-П» (група „Рамсинкс – 2“) са тествани в лабораторни условия за подобряване на качеството на оконтуряване на водо- и газоносни пластове чрез усъвършенстване на технологията за циментиране на производствени колони в нефтени и газови кладенци в сондажния отдел на „Укрбургаз“ (за междинни и производствени обсадни колони), особено при наличие на близко разположени продуктивни пластове и водоносни хоризонти с различни коефициенти на аномалии. Използването на хидрофобния тампонажен разтвор „Силпан-П“ се оказа целесъобразно. Физическите, химичните и механичните свойства на тампониращия хидрофобен разтвор „Силпан-П“ значително подобряват изолацията на продуктивните пластове при етапите на завършване на кладенеца.

Ключови думи: резервоарна колона, кладенец, цимент, хидрофобен разтвор, хидрофобна добавка

Introduction

The analysis of special literature sources and production and construction data show that in various fields from 10% to 50% of oil and up to 60% of gas wells have mutinous flows and are therefore partially or completely unsuitable for effective operation, so the success of well cementing operations is determined by the technique and technology of cementing processes, the quality of preparatory work, cementing material, and the completeness of replacement of drilling mud with cementing material.

The relevance of developing new cements for cementing is caused by the need to improve the quality of productive formations insulation at different stages of well commissioning and operation. As the depth of oil and gas wells increases, formation temperatures and pressures rise, making it more difficult to separate formations in wells.

Literature Analysis

The purpose of this work «Improvement of cementing of oil and gas wells production strings with hydrophobic materials of the «Ramsinks-2» group in various mining and geological conditions» is a laboratory study and industrial testing of the characteristics of the introduction of a new hydrophobic cementing solution with the following composition: nitrilotrimethyl phosphonic acid (NTFPA), «Ramsinks-2» hydrophobising additive, and PCT–1–100 grouting cement (further «Silpan-P» reagent), (Nalyvaiko, 2005; 2021).

A wide variety of geological and technological conditions for drilling and cementing wells necessitated the development of special cementing cements. Among them are slag-sand cements, which are used for cementing oil and gas wells at elevated temperatures, UShTS weighted slag cement plugging cements, used in conditions of abnormally high reservoir pressures (AHRP) at temperatures from 80 to 250°C, weighted grouting cements for moderate temperatures WGC, which are used for cementing casing strings at a temperature of 50-100°C in the conditions of the AHRP and intervals of salt deposits (Gleeson et al., 2010; Oreshkin, 2010).

Ukrainian scientists M. A. Myslyuk, I. Y. Rybchych, Y. S. Kotskulych, V. M. Svitlytsky, and D. V.Oreshkin made a significant contribution to the development of such issues as accident prevention, fastening, cementing, and plugging materials (Oreshkin, 2010).

At the same time, due to their physical-mechanical and physical-chemical properties, the existing grouting solutions (for example PCT 1-100) do not fully meet the quality requirements for the cementing of production wells.

Previous experience with various grouting materials

Nowadays, in order to improve the quality of grouting cement mortars, various additives are added to their production to improve their properties. We have proposed the latest cement mortar containing the hydrophobic additive «Ramsinks-2». This cement mortar (hereinafter referred to as «Silpan-P» cement mixtures) is intended to be used when passing through intervals of productive formations, taking into account specific geological and technological conditions, and to prevent intercasing flows during cement hardening. The mechanism of action is to regulate the technological parameters of the cementing mud with silicon-organic materials from the «Ramsinks-2» range, which leads to an overall improvement in the quality of the well cementing technology (Nalyvaiko, 2005).

Previous experience with various grouting materials allows us to foresee the possibility of creating a wide range of formulations with differentiated strength gain rates. The grouting cement must be well wettable and at the same time hygroscopically low.

The properties of hydrophobic cement that determine its technical and economic efficiency are as follows:

- hydrophobising properties facilitate the grinding of cement clinker, i.e., they intensify the grinding of cement, which increases the productivity of grinding plants at factories;

-hydrophobised cement powder is practically non-hygroscopic, so it is able to retain its activity during long-term storage even in humid conditions.

The hydrophobic additive should not reduce the strength of the cement stone, increase its permeability, or increase the viscosity of the mortar; it should prolong the preservation of cement by reducing its hygroscopicity (Iken et al., 2003).

The physical and mechanical properties of existing grouting cements and the «Silpan-P» hydrophobic grouting compound were studied in the laboratory and it was proven that the strength of the «Silpan-P» compound increased by 3-5 times and the water separation by up to 10 times.

The scientific novelty of the proposed technical solution is that, in comparison with the existing ones, it is proposed to produce and use hydrophobic grouting fluids with lower grouting fluid density ranges, high stability, improved pumpability, and high strength of the hardened stone, which guarantees the reliability of isolation of productive horizons.

The use of PTC 1-100 cement is widely recognised. Additionally, there is some experience with the «Ramsinks-2M» hydrophobic material. This material has successfully undergone industry laboratory tests at Ukrburgaz in Poltava, as well as in the physical research sector of the rock research department at UkrNDIGas reserves in Kharkiv, followed by pilot tests at Ukrnafta's fields. The material exhibited insulating effects on the pore surfaces of the reservoir rock. According to the authors, this physicochemical mechanism, when combined with PTC 1-100 cement, is expected to significantly enhance the properties of cementing materials, ultimately preventing formation flows.

The use of the «Ramsinks-2» hydrophobic material in the manufacture of the «Silpan-P» grouting cement mixture («Ramsinks-2» hydrophobic additive + PCT-1-100 + NTFPA) helps to increase the elasticity of PCT-1-100, prevents uneven concentration of fillers, and also prevents delamination of the mixture, increases resistance to aggressive factors, and increases their durability. High water resistance is achieved through the fine decomposition of hydrophobic particles in the SMN-20 mixer (Klymenko, 2016; Nalyvaiko, 2021).

These advantages of the newest «Silpan-P» hydrophobic cementing material will allow the use of these hydrophobic cements for cementing oil and gas wells in the AHRP zones, which meets the criterion of industrial use.

Laboratory tests

Laboratory tests were conducted using a mixture of PTC 1-100 cement and «Ramsinks-2» hydrophobic material.

Test conditions:

- room temperature 20 °C;
- atmospheric pressure 742 mm Hg; air humidity 78 %;
- pressure in the autoclave unit - 450 atm, temperature 75 °C.

The main indicators of the quality and effective use of the «Ramsinks-2» additive are: hydrophobic effect (degree); water absorption of cements and mortars; strength; water resistance; plasticity, etc.

To form the cement stone from the «Silpan-P» cement mixture, the A-2.00.000.IE autoclave unit was used in combination with a special device for installing metal molds with samples, whose function is to prevent sample destruction.

Cylindrical stone samples of «Silpan-P» cement mixture 39.5~1.0 mm long and 26~1.0 mm in diameter were previously formed in specially made metal molds in an autoclave unit. VLC-500 electronic scales were used to weigh the samples with the molds.

The selection of optimal ratios of PTC 1-100 and the «Ramsinks-2» hydrophobic material in laboratory conditions was 1:0.001, 1:0.002, 1:0.003, 1:0.005, 1:0.008, which ensures the required density of the grouting solution and the rate of strength gain with high operational parameters of the stone.

Object, subject, and methods of research

The theoretical principles of the research are based on the ability of «Silpan-P» hydrophobic substances from the «Ramsinks-2» group of materials to influence the physical, mechanical and physicochemical properties of existing grouting cement mortars (e.g., PCT 1-100).

Object of research. Samples of cement mortars of the «Silpan-P» group, which, when hardened, ensure high-quality contact of cement stone with casing and rocks, and the technology of their use in well casing.

Subject of research. The effect of hydrophobic cementing materials of the «Silpan-P» group on the hydration kinetics and technological properties of cement mortars, which significantly affects the quality of cementing production wells.

Research methods. The well-known methods of processing and analysing industrial data, methods of planning experiments and statistical methods of processing and analysing the results of experimental studies were used in the work. Experimental studies of the samples were carried out in the laboratory of Poltava Drilling Division of Ukrburgaz.

The hydrophobic effect was determined by laboratory testing for the degree of hydrophobicity of PCT 1-100 cement with the «Ramsinks-2» additive. Samples of cement weighing 200 g were poured with the volume of water required to obtain a normal density of cement dough, left to rest, and the time of water absorption by the cement was noted.

The optimal additive to the «Ramsinks-2» grouting fluid, depending on reservoir thermobaric conditions, is 0.02-0.03% by weight of the binder. Further increase in the additive content leads to a decrease in the strength of the cement stone, which,

in our opinion, is due to the pronounced hydrophobic properties of «Silpan-P».

The data obtained during the test with different values of «Ramsinks-2» as a percentage of cement weight (0.2, 0.25, 0.3 %) are given below in Table 1.

Table 1. *Effect of the amount of hydrophobic additive on cement properties*

Cement brand and type	Cement sample weight	Name of the additive	Additive content (% by weight of cement)	NGTC normal density of c/dough, ml	Degree of hydrophobicity of cement, min.
PCT1-100	200 g	-	-	95 ml	8
PCT1-100	200 g	«Ramsinks – 2»	0,02	95 ml	11
PCT1-100	200 g	«Ramsinks – 2»	0,025	95 ml	14
PCT1-100	200 g	«Ramsinks – 2»	0,03	95 ml	17

According to the results of laboratory tests of the degree of hydrophobicity of PCT1-100 grouting cement with the «Ramsinks-2» hydrophobic additive, it was found that the degree of hydrophobicity of the cement depends on the amount of «Ramsinks-2» additive in percentage (%) by weight of the cement.

The scheme for selecting formulations with the required parameters and studying the physical and mechanical properties of the grouting stone is standard and is performed at temperatures of 70°C, 100°C, 130°C, 160°C and corresponding pressures by equalising the proportions of PTC 1-100 cement and «Ramsinks-2» hydrophobic material for these conditions. When mixed, a uniform grouting solution is formed. The samples are stored under hydrobarothermal conditions for 1, 7, and 28 days.

The «Ramsinks-2» additive is used directly during cementing operations to prevent reservoir fluid migration (inter- and inter-conveyance flows).

When completing wells, the following reservoir parameters are of the greatest interest: formation (or pore) pressure, fracturing pressure, porosity, geostatic pressure, as they, in turn, allow us to identify such important technological parameters as drilling mud density, permissible speeds of the strings in the open hole, string sizes, well design, etc.

Based on the laboratory studies of the technological parameters of the cement slurry and cement stone, it is recommended to use the «Ramsinks-2M» admixture to the cement slurry with Portland cement for cementing oil and gas wells (for intermediate and production casing) at Ukrburgaz in order to prevent the formation fluids migration (interstitial and formation flows), as well as another direction of implementation, namely, for the purpose of repair and insulation works at Ukrburgaz wells, which in turn will ensure a significant technological and economic effect from the implementation.

Depending on reservoir thermobaric conditions, the optimal additive to the «Ramsinks-2M» grouting fluid is 0.02-0.03% by weight of the binder. Further increase in the additive content leads to a decrease in the strength of the cement stone, which, in our opinion, is due to the pronounced hydrophobic properties of «Silpan-P».

In our work, we selected grouting fluid formulations based on PCT 1-100 and ST, taking into account the actual temperature, and utilising cements, chemicals, and mud for use on this drill.

In order to exclude the possibility of premature thickening of the grouting solution before it is washed off during the analysis, it is necessary to stop the stirrer of the KC-3 consistometer after 3 hours for 0.5 hours with a sequential continuation of the analysis. The time of the thickening of the plugging solution should correspond to the calculated one plus 1 hour of reserve for the possibility of accelerating the setting and thickening of the solution in contact with bischofite. The required amount of hydrophobic grouting mixture was made by dry mixing PTC 1-100 cement and NTFPA additive to the «Ramsinks-2» hydrophobic material.

«Silpan-P» cement mix is used directly during cementing operations in the well. When mixed, a uniform grouting solution is formed.

Below are the results of laboratory tests on samples of PCT-I-100 cement stone with «Ramsinks-2» hydrophobic admixture.

Conditions for conducting research:
- PCT-I-100 grouting cement;
- W:C=0.50.
- The specific gravity of cement is 1.83.
- Temperature in the autoclave - 75°C.

Study No. 1 (PCT-I-100+0.03% NTFPA + 0.2% «Ramsinks-2»)
Water separation:
- PCT-I-100 + 0.03% NTFC - after 2 hours = 6.8%;
- PCT-I-100 + 0.03% NTFC + 0.2% «Ramsinks-2» = 4.7%.
- The specific gravity of «Ramsinks-2M» is 1.82.
- Thickening time up to 30 UOC = 56 minutes.

Study No. 2 (PCT-I-100+0.06%NTFPA +0.25% «Ramsinks-2»)
Water separation:
- PCT-I-100 + 0.06% NTFC - after 2 hours = 6.8%.
- PCT-I-100 + 0.06% NTFC + 0.25% «Ramsinks-2» = 4.7%.
- The specific gravity of «Ramsinks-2» is 1.82.
- Thickening time up to 30 UOC = 1 h 40 min (during the analysis in the autoclave, the mixing paddle separated)

Study No. 3 (PCT-I-100 + 0.06% NTFC + 0.3% «Ramsinks-2»)
Water separation:
- PCT-I-100 + 0.03% NTFC - after 2 hours = 6.8%.
- PCT-100 + 0.03% NTFPA + 0.2% «Ramsinks-2» = 5,4%.
- The share of «Ramsinks-2» is 1.82.
- Thickening time up to 30 UOC = 40 min.

Study No. 4 (PCT-100 +0.06% NTFPA+0.25% «Ramsinks-2»)
Water separation:
- PCT-I-100 + 0.03% NTFPA - after 2 hours = 6.8%;
- PCT-100 + 0.03% NTFPA + 0.2% «Ramsinks-2» = 4,7%.
- The share of «Ramsinks-2» = 1.82.
- Thickening time to 30 UOC = 2 h 30 min.

Flexural strength of PCT-I-100 + NTFPA according to DSTU B V 2.7.86-99 = 3.5 MPa.

Flexural strength of PCT-I-100 + 0.06% NTFPA + 0.3% «Ramsinks-2» = 9 MPa.

Rheological parameters are an important characteristic of the cementing mud. They largely determine the amount of hydraulic resistance during well cementing, and affect the completeness of the displacement of the mud and the annulus.

The very purpose of the two-part complexes is to maintain the required pressure on fluid-saturated formations during the process of cement hardening. The formation of a coagulation-crystallisation cement structure is accompanied by a decrease in pressure at the wellbore. Therefore, it is necessary to select the grouting slurry column so that the upper part of the column is in a liquid state before the start of hardening and the lower part reaches the required strength. The value of such strength, when the body of the cement ring becomes impermeable to the fluid, reaches about 1.5 MPa.

The technical parameters of the latest hydrophobic grouting solutions (mobility, density, water separation, pumpability, etc.) were confirmed in the laboratory in accordance with the standard requirements of the relevant devices.

The strength value was measured on a PSU-2 hydraulic press. The rheological properties of grouting solutions were studied on a Reotest-2 rotational viscometer. The corrosion resistance of cements in various aggressive environments was studied at temperatures from 20 to 80°C.

In laboratory conditions, research was conducted to determine the absolute gas permeability of cement stone samples with PCT-1-100 and «Ramsinks-2» hydrophobic additive. The analyses were performed in accordance with GOST 26450.0-85 - GOST 26450.2-85.

Table 2. *Results of determining the absolute gas permeability of cement stone samples with PCT-1-100 and «Ramsinks-2» hydrophobic*

Lab. no. of the sample	Sample formulation	Gas permeability, a x 10^{-15} m^2
40443	cement stone from PCT-1-100	0,15
40444	cement stone from PCT-1-100, 0.2% with «Ramsinks-2» additive	
40445	cement stone from PCT-1-100, 0,25% with «Ramsinks-2» additive	0,10
40446	cement stone from PCT-1-100, 0,3% with «Ramsinks-2» additive	0,05
40447	cement stone from PCT-1-100, 0,35% with «Ramsinks-2» additive	0,04
40448	cement stone from PCT-1-100, 0,4% with «Ramsinks-2» additive	0,04

Laboratory studies of the permeability of cement stone samples conducted at the Department of Rock Research and Gas Reserves Estimation of the Ukrainian Research Institute of Natural Gases have shown that the «Ramsinks-2» additive to the cementing mud significantly reduces the permeability of cement stone to gas, which also allows for increased oil and gas well cementation.

Laboratory tests of the grout and cement stone carried out in the laboratory of grouting solutions of the Poltava Grouting Department established that the «Silpan-P» hydrophobic grout is made of PCT1-100 grouting cement and an admixture of NTFPA and «Ramsinks-2» material:

a) does not significantly reduce the technological parameters of grouting mortar and cement stone, which are determined by the current standards: «Grouting cements. Test methods. DSTU B.V. -2.7-86-99 (GOS 26798.1-96)»;

b) improves the strength characteristics of cement stone, in particular the flexural strength, which increases the durability and manufacturability of the well construction.

The use of «Silpan-P» hydrophobic cement mortars will significantly reduce the migration of reservoir fluids. The use of various types of cements with the «Ramsinks-2» hydrophobic additive will increase the success and efficiency of Ukrburgaz 's operations.

Laboratory analysis of the technological parameters of the cement slurry and cement stone suggests the use of the «Ramsinks-2» additive in Portland cement mixtures for cementing oil and gas wells (intermediate and production casing) at Ukrburgaz. This approach helps prevent the migration of formation fluids, including interstitial and formation flows, and can be utilized for repair and insulation work, delivering notable technological and economic benefits.

The optimal concentration of the «Ramsinks-2» additive in the grouting fluid ranges from 0.02% to 0.03% by weight of the binder, based on the reservoir's thermobaric conditions. Increasing the additive content beyond this range may decrease the strength of the cement stone, likely due to the pronounced hydrophobic properties of «Silpan-P».

The selection of grouting fluid formulations based on PCT 1-100 and ST was carried out considering the actual temperature, using cements, chemicals, and mud specific to the drilling operations. To avoid premature thickening of the grouting solution before it is fully washed off during analysis, the stirrer of the KC-3 consistometer should be stopped for 0.5 hours after 3 hours of operation, with the analysis then continuing sequentially. The thickening time of the plugging solution should match the calculated time plus a 1-hour reserve, allowing for potential acceleration of setting and thickening when in contact with bischofite.

The required amount of hydrophobic grouting mixture was prepared by dry mixing PTC 1-100 cement with the NTFPA additive and the «Ramsinks-2» hydrophobic material.

The technological parameters of the PCT 1-100 cementing slurry combined with the «Ramsinks-2» hydrophobic admixture indicate that the latest hydrophobic solution, «Silpan-P», should be used for cementing oil and gas wells (intermediate and production casing) at Ukrburgaz. This approach effectively prevents the migration of formation fluids (both interstitial and formation flows) and is also suitable for repair and insulation work at Ukrburgaz wells, offering substantial technological and economic benefits.

For our study, we developed grouting fluid formulations using PCT 1-100 and ST, considering the actual temperature and incorporating suitable cements, chemicals, and mud for the drilling process. To avoid premature thickening of the grouting solution during analysis, the stirrer of the KC-3 consistometer was paused after 3 hours for 0.5 hours before resuming analysis. The necessary hydrophobic grouting mixture was prepared by dry mixing PTC 1-100 cement with the NTFPA additive and «Ramsinks-2» hydrophobic material.

In conclusion, it should be noted that the use of «Ramsinks-2» at the stage of well operation is promising for increasing the effective life of depleted fields. For the technological

implementation of such a solution, the equipment that will initially be used for the production and injection of the proposed grouting solutions can be mainly used (Nalyvaiko, 2021).

Previous experimental studies conducted at the laboratory of the Central Ukrainian National Technical University also evaluated the impact of «Ramsinks-2M» on the conditions and kinetics of gas hydrate formation (Klymenko, 2016). It has been found that under certain (static) conditions, «Ramsinks-2M» behaves as a surface active substance that does not dissolve in water, but remains on its surface, thereby forming a «protective film» between water and gas. In this case, there is no contact area between gas and water and no hydrate formation occurs.

However, when oscillating the crystalliser, the onset of the hydrate formation process when using «Ramsinks-2M» began much earlier compared to the experiment in which only distilled water was used. The most significant effect on the acceleration of the hydrate formation process was the concentration of «Ramsinks-2M» of 50 ppm, and at concentrations above 200 ppm, the time of the onset of the hydrate formation process increased significantly.

In other words, under certain conditions, «Ramsinks-2M» can be a promoter of hydrate formation, and under other conditions, an inhibitor, which should be taken into account when using it in hydrocarbon production systems.

In the course of a series of experiments, a clouding of the observation window was also noticed, and after removing the glass, a thin layer of strongly adhered «Ramsinks-2M» microparticles was found on it.

Results

1. In comparison with the existing solutions, the proposed technical one will allow to obtain «Silpan-P» hydrophobic grouting fluids with lower ranges of grouting fluid density, high stability, good pumpability, and high strength of the hardened stone, and which guarantees the reliability of isolation of productive horizons.

2. The conditions are determined for the use of «Silpan-P» hydrophobic cement mortars of various compositions to reduce the migration of reservoir fluids in various mining and geological conditions.

3. For the specific conditions of cementing production strings of well No. 101 of the Hadiach field, a «Silpan-P» hydrophobic cement grout from the «Ramsinks-2» group was developed and produced, which provides high quality separation of water and gas bearing formations (Nalyvaiko, 2021).

4. The technology of application of «Silpan-P» hydrophobic cement grout from the «Ramsinks-2» group for delimitation of water and gas bearing formations was developed. These cementing materials were used in deep wells at Ukrburgaz in difficult mining and geological conditions of the DZ, which provided a significant technological, economic and environmental effect (Nalyvaiko, 2021).

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