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CONSIDERATION OF THE GEOLOGICAL AND TECHNICAL CONDITION OF THE RESERVOIR AND WELLBORE BOTTOM ZONE IN THE SELECTION OF THE CEMENT COMPOSITION APPLIED TO THE PRODUCTION WELLBORE FLOW ZONE

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ABSTRACT
Production well filter zone must comply a number of technical and economic requirements to maintain design oil production parameters. However, despite the relevance of the problem, in the thematic literature and regulatory documentation on cementing operations, the issue of taking into account geological and technological, physical, chemical and geomechanical parameters of the productive formation around the producing wells is practically not paid to attention. Mainly, there are considered the cementing process in drilling operations along the wellbore as a whole. This article presents the results of laboratory, experimental and theoretical studies related to the development and application of technology that ensures the cementing works quality and safety, aimed at supporting the production wells filter zone in fields operating under «Azneft» PU. A technology has been developed for a reasonable and economical selection of materials and component composition, regulators and additives for setting and hardening of cement slurry, taking into account factors affecting the strength properties of the resulting cement stone in contact with the aggressive environment of the reservoir system. Technology is based on a comparative of the stresses arising in the resulting cement stone and drainage zone, checking the properties of the cement powder used in accordance with the filter zone current state. By using the research results carried out some of regulatory documents were adopted regulating the choice of cement composition for the well filter zone according to the formation geological and technological parameters. Application of the proposed approach is possible for wells of any field.

KEYWORDS:
Cementing;
Cement slurry;
Well filter zone;
Cement slurry flow ability;
Lightweight cement slurry;
Cementing of well filter zone with maintenance of its capacity.

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1. Introduction

Like any technical structure, a production well must meet a number of technical, technological and economic requirements aimed at achieving the design parameters of its operation. The problem of ensuring the strength properties of the the near-borehole filter zone of wells is solved, most often, by securing unstable rocks and isolating aquifers through a cementing operation. The result of a successfully completed operation is the minimization of technological and economic risks during the operation of wells, the reduction of the overhaul period of wells, as well as the improvement of the quality indicators of well operation.

To obtain effective results from performing this operation and selecting a composition that corresponds to the geological and technological indicators of the exploited productive formation, the qualitative properties of both the cement powder used and the selection of the necessary additives to the cement slurry are important. The fundamental requirements in this case are the preservation of the fluidity of the solution during compression, which makes it possible to deliver the solution to the cementing zone without additional phase resistance, and the technical provision of stable contact of the resulting cement stone with the rocks that make up the walls of the well. At the same time, both high values of effective porosity and permeability of the resulting cement stone must be maintained, ensuring its long-term strength in formation conditions, and the ability of the near borehole zone to selectively filter hydrocarbons into the well in thermobaric conditions aggressive for cement, enhanced by contact with such formation fluids as formation water high mineralization, microbiological contamination, mixtures of reservoir gases.

An important condition for ensuring high-quality fastening of the well filter zone is control over compliance with the standard properties of the materials used, according to existing regulations and standards. This condition is a key factor in the success

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Reservoir and petroleum engineering

of the activities, as it ensures that the cementing process meets safety requirements and long-term efficiency. Certified materials have the necessary strength and resistance to aggressive environments such as acids, salts, high pressure and temperature, and provide a tight connection between the cement and the rocks of the near-borehole zone, thereby ensuring reliable supporting and selective capacity of the filter zone.

This article presents the results of research related to the development and application of effective technology to ensure the quality and safety of cement work aimed at strengthening the downhole filter zone of wells in fields operating under «Azneft» PU, but the application of the proposed technology is possible for wells of any oil and gas field.

2. Basic requirements for the properties of cement slurry used for consolidation a filter zone of production wells

Information about the most common types and brands of cement used in well cementing is given in the literature [1-4]. In this paper we will give only a brief description of the materials that were used in the course of the research. It should be noted that the chemical products used for laboratory and experimental research are certified in terms of quality and origin. In accordance with the applicability indicators, the following groups of cementing materials were used:

– basic and modified grouting cements and mortars. Basic grouting cements have been used as the main component of modified compositions, including for disposable purposes;

– special additives that can be used both independently and to modify the properties of cement slurries. The cementing materials used were classified according to:

- Application temperature:
  – Low temperature (<15°C);
  – Medium temperature (15-40 °C);
  – Relatively high temperature (40-90 °C);
  – High temperature (90-160°C);
  – Critically high temperature (>160 °C).
- According to the density of the resulting solution:
  – Lightweight, with density <1400 kg/m^3;
  – Lightweight, with a density of 1400-1700 kg/m^3;
  – Normal, with density 1650-1950 kg/m^3;
  – Weighted, with a density of 1950-2300 kg/m^3;
  – Heavy, with density >2300 kg/m^3.
- According to the characteristic behavior during setting and hardening:
  – Fast and late setting;
  – Corrosion resistant;
  – Expanding;
  – Plug formers;
  – Particularly mobile;
  – Solutions with low fluid loss, reinforced with special strength fillers, etc.

3. Factors influencing the strength properties of the resulting cement stone

The strength of cement stone in reservoir conditions depends on many factors:

1. The influence of formation fluids due to their composition and physical properties of the environment [5].

To study the influence of water on the characteristics of the cement slurry and the resulting cement stone, water of various compositions (sea, formation, fresh) was used in a wide temperature range (30, 40, 50, 60, 75 °C). The analysis of the composition of formation waters is carried out in accordance with the enterprise standard [7]. Depending on the goals and objectives of the study, standard equipment was used to analyze the composition of formation and sea water, including a spectrophotometer, chromatograph, mass spectrometer, pH meter, microscope, etc.

2. Characteristics of the stress-strain state near the wellbore zone [6].

The geomechanical properties of the near-wellbore formation zone are assessed in accordance with the results of quantitative and qualitative analysis of its stress-strain state. To assess the local forces acting on the cement stone from the formation, it is proposed to calculate the time-varying values of local stresses in the radius of the near borehole zone. A comparative analysis of the forces acting on the injected volume of cement slurry and the resulting cement stone from the formation side, with the limiting values determined by the strength characteristics of the materials used, makes it possible to predict the stability of the fastening during the operation of the well. The rock rupture gradient around the well located in a horizontal and homogeneous formation is determined from the expression [6,11]:

$$F = 3\sigma_{rr} - \sigma_{\varphi\varphi}cos(\alpha) + \sigma_{zz}sin(\alpha) + T + p_{for} \quad (1)$$

where T is the tensile strength of the rock, Pa; p_{for} – formation pressure, Pa; α – the angle of deviation of the well from the vertical, degrees; σ_{rr}, $\sigma_{\varphi\varphi}$, σ_{zz} – average normal stresses around the well, which are calculated based on the rheophysical parameters of the formation system, Pa.

On the other hand, the pressure P_{out} required to push the cement mixture, volume V, is determined as follows [12]:

$$P_{out} = P_{inj} - \rho g(L - l) - \frac{Q\gamma J(t_1 - t_2)}{2\pi h \alpha_1 R_{max} \ln \frac{R_{max}}{r_c}} \quad (2)$$

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

The volume of cementing material required to support the filter zone and create the appropriate pressure is determined in accordance with the expression:

$$V = 2\pi m_0 \left[\frac{\alpha_2 \Gamma \delta^3 J \gamma}{12\mu} \left(t_1 - \frac{L}{v_k} - \frac{l}{v_{к.п.}} \right) \right]^2 \quad (3)$$

where J – pressure gradient; g – gravitational acceleration, m/s^2; h – filter power, m; r_w – well radius, m; R_{max} – maximum radius of spread of the cement mixture, m; γ – specific gravity of the cement mixture, N/m^3; ρ – solution density, kg/m^3; μ – plastic viscosity of the cement mixture, Pa·s; t_1 – time during which the cement mixture reaches the maximum consistency at which mobility is lost (30 Vs), s; t_2 – time of pumping the cement mixture to the formation; P_{inj} – injection pressure at the wellhead, Pa; P_{exit} – pressure at the exit from the annulus, Pa; Q – cement mixture consumption, m^3/s; L – well depth, m; l – the distance from the borehole to the filter bottom, m; v_c, $v_{a.s.}$ – respectively, the speed of move-ment inside the column and in the annular space, m/s., m_0 – cavernosity of the fractured massif; α_1 – crack curvilinearity coefficient, ($\alpha_1 \geq 1.0$); d – density of cracks, 1/m; δ – average volumetric crack opening, m.

Based on the results of calculating these characteristics, it is possible to predict the time and place of the destructive effect of these forces on the well filter lining. Calculation formulas for stresses arising in the wellbore zone, used to quantify the stress-strain state of the reservoir system, differ from each other depending on the lithological composition of the rocks that make up the drainage zone of the well, the depth of the filter and the inclination angle of the wellbore in the filter zone. Geological and technical information characterizing the«well-formation» system is used as initial information. When carrying out stress calculations in conditions of insufficient information about the values of the physical parameters of the reservoir system, averaged values of physical and mechanical characteristics corresponding to the filter zone of rocks and reservoir fluids saturating them are used. In this case, the results are averaged.

The objectives of the laboratory studies were as follows:

– Selection of cementing materials and the component composition of the cementing solution for lining the bottomhole zone, taking into account the geological and technological parameters of the formation around the production wells depending on the temperature of the formation and the composition of formation waters (table 1-2);

– Determination of the influence of the composition of technical, sea and formation waters on the rheological parameters of cement slurry (table 3-4);

– Analysis of changes in setting time and tensile strength of cement mortar prepared with different types of water, depending on temperature;

– Analysis of the quality of the cement powder used.

The cement slurry is characterized by such parameters as density, setting time, permeability, strength of the cement stone created, etc. The quality of the cement used is assessed according to API standards [7]. Measurements of these parameters are carried out in laboratory conditions using the following certified equipment:

– electronic balance (CUX -420H);

– thermostat (WCB -11);

– Vikat apparatus (TY -2504-2550-80 No. 468);

– high pressure and temperature consistometer (HPHT Consistometer model 7222);

– press (Digital compressive strength tester 4207D).

Depending on the type and quality of the cement used, the physical, mechanical and chemical properties of the cement slurry obtained from it, in accordance with the results of the analysis of the geomechanical properties of the near-bottomhole formation zone, special chemical additives are proposed that allow the formation of modified cement compositions with the required characteristics.

Based on the research conducted, a number of methodological and technological documents have been developed and, in accordance with the established

Table 1

Analysis of cement samples obtained from various oil and gas production departments for February 2024

No.	OGES	Water cement factor	Water separation ,%	Grasping: Tempera-ture (C⁰)	Grasping: Pressure, MPa	Grasping: Compressive strength of cement stone, MPa	Grasping: Time (hour : minute) Start	Grasping: Time (hour : minute) End	Note
1.	«Neft Dashlari»	0.44	3.4	52	35.6	3.12	1:00	1:50	Complies with API 10A standard.
2.	«N.Narimanov»	0.44	3.7	52	35.6	2.35	1:25	2:30	Does not meet API 10A standard, setting time exceeds 2 hours.

Scientific Petroleum
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Reservoir and petroleum engineering

Table 2

Physico-mechanical characteristics of water cement mortar solution obtained during experiments conducted in February 2024 («Neft Dashlari» OGPD)

No.	Well No.	Horizon	Material under study	Well filter, m	Water cement factor	Tempera-ture °C	Spreada-bility, 10^{-2} m	Density g / cm^3	Setting time hour - minute		Tensile strength, MP a
									Start	End	
1			Cement Sea water		0.5	50	20.0	1.80	2-45	3-20	22.3
2	2687	QA-2a	Cement Formation water	1376-1373	0.525	50	19.0	1.79	3-10	3-45	12.9
3	2475	QA-2a	Cement Formation water	912-908	0.525	50	20.0	1.80	2-50	3-30	21.3
4	2333	FLD	Cement Formation water	1442-1440	0.525	50	19.0	1.79	3-20	4-00	13.8
5	2425	VIII	Cement Formation water	1689-1680	0.525	40	19.0	1.80	3-15	4-10	21.6
6	2225	IX	Cement Formation water	446-444	0.525	40	20.0	1.80	3-30	4-20	15.9

Table 3

The influence of substances included in the formation water on cement stone

Formation water type	Compounds included in formation waters	Changes occurring in cement mortar and cement stone
Palmer›s first salinity S 1	NaCl, KCl, Na_2SO_4, K_2SO_4	When cement mortar comes into contact with salts NaCl , KCl in a highly saline environment, corrosion of the cement stone occurs. As the pore fluid becomes saturated with these salts, the water is used for hydration and the salts crystallize in the pores. As the density of water increases, the cement mortar becomes thinner. As the specific gravity of the cement mortar increases, sediment forms. $Na_2SO_4 + Ca(OH)_2 = CaSO_4 + 2\,NaOH$ First, the porosity of the cement stone decreases with an increase in its strength, then it undergoes destruction due to crystallization pressure.
Palmer›s second salinity S 2	$CaCl_2$, $MgCl_2$, $CaSO_4$, $MgSO_4$	An insoluble precipitate is formed: $CaCl_2$, $MgCl_2$, $CaSO_4$, $MgSO_4$ $MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$ $MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$. $Mg(OH)_2$ settles on the surface of the cement stone and forms a semi-permeable barrier that destroys the cement stone.
First Palmer alkalinity A 1	Na_2CO_3, $NaHCO_3$, Na_2S, K_2CO_3, HCO_3, K_2S	Acts as a retarder, preventing rapid setting.
Second Palmer alkalinity A 2	$CaCO_3$, $Ca(HCO_3)_2$, $MgCO_3$, $Mg(HCO_3)_2$	The positive effect of $CaCO_3$ on the stability of Portland cement is explained by the reaction of carbonate with aluminum minerals contained in the clinker. As a result, calcium hydroaluminate is formed $3CaO\ Al_2O_3\ CaCO_3\ 11H_2O$.
Acidity pH	H_2S, H_2CO_3	Calcium hydrosulfide $Ca(HS)_2$ is formed, which is highly soluble in water and easily washed off from cement stone: $Ca(OH)_2 + 2H_2S = CaS + 2H_2O$ $CaS + H_2S = Ca(HS)_2$ Corrosion occurs by the same mechanism: $Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2H_2O$ $CaCO_3 + H_2CO_3 = Ca(HCO_3)_2$

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

Table 4

Temperature conditions for using setting and hardening regulators

Well temperature	Cement	Recommended reagents and their combinations
0-10 °C	Portland cement	$CaCl_2$, NaCl, NaCl + $CaCl_2$, KCl, K_2CO_3
0-20 °C	Portland cement	$CaCl_2$, NaCl, $CaCl_2$ + NaCl, NaOH, Na_2CO_3, Na_2SO_4
20-75 °C	Portland cement	$CaCl_2$, NaCl, NaOH, Na_2CO_3, Na_2SO_4
75-100 °C	Portland cement + sand, slag cement	Accelerators are used only in combination with retarders-plasticizers and retarders- reducers of water output. $CaCl_2$, NaCl, Na_2CO_3, Na_2SO_4, NaOH, K_2CO_3
> 100 °C	Portland cement and slag Portland cement, slag cement	Used as a retarder Na_2CO_3, NaOH together with retarders-plasticizers and retarders-reducers of fluid loss

procedure, adopted for use, regulating the conduct of cementing work in the filter zone of production wells, taking into account the geological and technological indicators of the near-bottomhole zone of the productive formation of the field [8, 9].

Determining the quality of cement, assessed according to API standards, is important when selecting a cement composition for lining the filtration zone of production wells. Thus, samples of the same brand of cement taken from different oil and gas production units for quality analysis may show different results (table 1). This is due to the fact that the rheological characteristics of cement powder can change over time depending on the physical properties of the material, environmental conditions and equipment used for its storage, and the reasons for the deterioration of the quality of cement powder are still not fully understood [10].

4. Results of the research

Primarily, the influence of the mass fraction of water in the cement mortar on its rheological parameters was studied. Simple water-cement mixtures were prepared without adding any reagents. Analysis of these mixtures showed that viscosity values decrease as the mass fraction of water increases (fig. 1).

The thixotropic properties of cement mortar with a water-cement ratio of 0.44 were analyzed at different temperatures (fig. 2). The hysteresis curve indicates the degree of thixotropy. Cement mortar at room temperature 25 °C exhibits less thixotropy than at higher temperatures. The reason for this is the increase in the degree of hydration at high temperatures. A smaller area of the hysteresis curve indicates that the structure is unstable, therefore the fluidity of the cement mortar is better at this time. As it can be seen from graph 2, the reason for the high shear stress at low shear rate at 60 °C is that the cement slurry forms a gel structure at high temperatures.

It was also found that one of the main factors influencing the physical and chemical properties of the cement slurry is the chemical composition of formation waters. It has a great influence on the fluidity of the cement slurry, setting time parameters and the strength of the resulting cement stone. As a confirming example, we present data from experimental studies to determine the physical - mechanical characteristics of water cement mortar solution, obtained during experiments carried out on samples of cement and formation water from different productive hori-

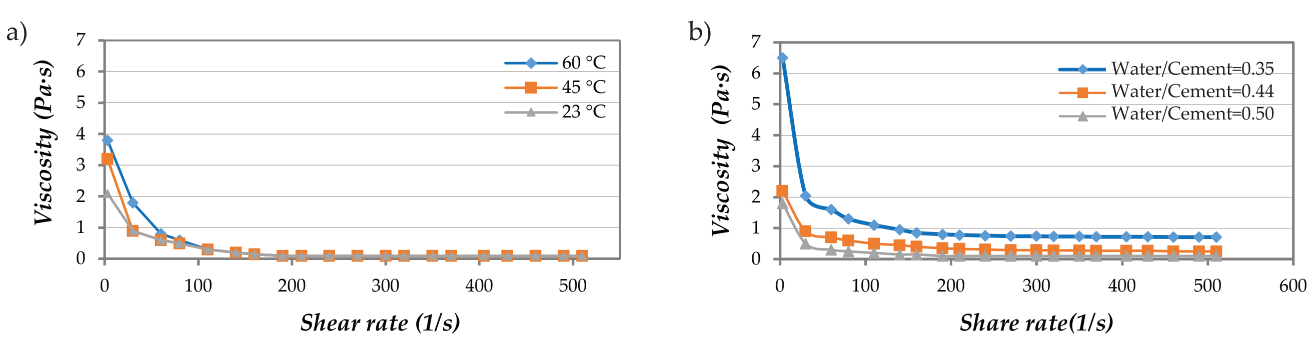

Fig. 1 Change in viscosity depending on the sliding speed at different values: a) temperature, b) water/cement ratio

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

zons taken at the wells of «Neft Dashlari» OGPD in February 2024 (table 1).

As it is known, the possibility of using cement mortar is determined by the setting time of the solution. The beginning and end of the setting process depends on the chemical and mineralogical composition of the cement, the ratio of the water-cement factor, chemical additives to the solution, temperature and pressure in the wellbore and near-borehole zone and, most importantly, on the composition of the formation water with which the cement is in contact. Based on the results of chemical analysis of formation water samples taken from the wells of the Absheron oil fields, it was determined that in some samples of formation water the ratio of the amounts of Na^+ and Cl^- ions is less than one. This is due to the presence of calcium chloride ($CaCl_2$) in these waters. In such an environment, crystallization corrosion of cement stone has the specificity of occurring in the pore volume, which is due to the growth in the pores of crystals of substances formed as a result of the chemical interaction of an aggressive environment with cement stone. Information on the influence of substances contained in formation water on cement stone is given in table 3. Taking these factors into account, the cement composition for lining and high-quality performance of insulation and repair work near the borehole filter zone must be developed individually according to the geological and technological parameters of each production well. Depending on these parameters, to control the setting and hardening time of cement, regulators of the setting and hardening processes (accelerators/retarders) are included in the composition of cement mortars. When choosing a reagent, as a rule, they are guided by the fact that the use of additives such as sodium and potassium salts of sulfuric acid (Na_2 SO_4 and K_2SO_4), calcium nitrate ($Ca(NO_3)_2$) are effective for cement mortars with low and average aluminum content. For cement mortars with high aluminum content, additions of chlorine-containing reagents are more effective. Recommendations for the temperature regime for the use of setting and hardening regulators are given in table 4. Increasing the amount of caustic soda (NaOH), potash (K_2CO_3), soda ash (Na_2CO_3), sodium chlorides, potassium chlorides and calcium (respectively: NaCl, KCl, $CaCl_2$) in cement mortar up to 3% causes a decrease in the strength of cement stone after a long period of hardening. When the content of sodium chloride is more than 5% and sodium carbonate is less than 1%, the rate of setting and hardening slows down. An increase in the amount of caustic soda, potash, sodium carbonate (soda ash), sodium, potassium and calcium chlorides in cement mortar up to 3% causes a decrease in the strength of cement stone after a long period of hardening. The introduction of more than 2% chlorides causes pipe corrosion. At high concentrations of chlorides in formation water, to reduce their concentration in the cement mortar, it is recommended to simultaneously use nitrites, nitrates and chromates of sodium, potassium and calcium (respectively: $NaNO_2$, $NaNO_3$, Na_2CrO_4, K_2CrO_4, $CaCrO_4$). Sodium and potassium sulfates cause corrosion if their content in the solution is more than 6%. To prevent pipe corrosion when cementing wells at positive temperatures, it is recommended to use inhibitors or organic electrolytes. It should also be taken into account that when adding sodium carbonate to cement solutions with a large amount of chlorides, as well as when closing wells with the injection of highly mineralized water, the fluidity of the cement solution can sharply decrease. When using accelerators, as a rule, the strength and resistance of cement stone to low temperatures is significantly reduced. For solutions of high-alumina cement, reagents containing chlorine ions are more effective. Cement mortars with additives of calcium nitrite with urea, calcium nitrate + urea, calcium nitrite-nitrate, calcium chloride + sodium chloride, nitrite-nitrate-calcium chloride additives are characterized by accelerated and very short thickening periods, which are less dependent on temperature. For this reason, in some cases, retarders are also used simultaneously with accelerators. The need to add moderators is determined experimentally. When determining which accelerators to use, it should be taken into account that some of them are retarders when the temperature increases or decreases (for example, urea).

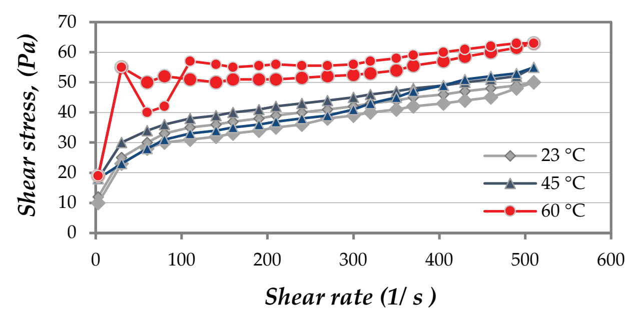

Fig. 2. Thixotropic properties of cement mortar with a water-cement ratio of 0.44

When preparing lightweight cement mortars for lining the bottom-hole zone of wells, cost-effective low-density additives were used, obtained on the basis of products and waste from the domestic industry of Azerbaijan. The following reagents were added to the cement composition: fireclay (25%), expanded clay (37.5%), carbonate (25%), bran (5%). By selecting additives it is possible to achieve cement savings of up to 25-30 % and reduce the density of conventional cement stone from 1900 kg/m³ to 1590 kg/m³. Laboratory stud-

Scientific Petroleum
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Reservoir and petroleum engineering

ies have shown that the resulting cement stone created on this basis is 35% lighter compared to cement stone obtained on a water-cement basis.

The procedure for preparing lightweight cement mortars is carried out at high temperatures. Due to their low density, lightweight cement mortars are able to move over longer distances in the drainage zone of the well, compared to mortars prepared on a cement-water basis. This allows to provide high-quality lining of the filter zone of deep production wells.

Based on the conducted research, technology and corresponding regulatory documentation for the selection of cement composition during cementing operations were developed, based on the individual characteristics of the well selected for this operation. A program, methodology and technological regulations for developing principles for justifying the choice of cement composition based on the geological and technological parameters of the formation and conducting analyzes according to API standards have been developed, agreed upon and approved [10].

5. Application of the research results when carrying out cementing operations in the filter zone of production wells in the department of PU «Azneft»

Currently, cementing operations in the filter zone of production wells, carried out at fields under the authority of PU «Azneft», are carried out in accordance with the developed technology. The technology was used at the «Neft Dashlari» (9 wells), «Gunashli» (26 wells), «Chilov» (4 wells), «Pirallahi» (11 wells), «Darwin» (2 wells), «Bibi-Heybat» (11 wells), «Yasamal Deresi» (1 well), «Lokbatan-Puta-Gushkhana» (6 wells), «Sangachal-Duvanny-Khara-Zira» (1 well), «Sadan» (3 wells), «Zaghly-Zeyva» (5 wells), «Karadag» (2 wells). Carrying out cementing work on selected production wells is carried out under the supervision of technology developers in accordance with API standards and the requirements given in the guidelines to ensure an individual approach to each well and the technological efficiency of cementing the filtration zone of production wells.

Conclusions

1. The measures related to cementing the filter zone of production wells, while preserving its throughput capacity, should take into account the pressure gradient required to affect the reservoir, taking into account its geomechanical and filtration properties that change during field operation.
2. During isolation and repair works of the near-wellbore filter zone, the time of setting and hardening of cement in cement mortars is controlled by means of setting and hardening process regulators, the choice of which is made individually according to the geological and technological parameters of each production well.
3. The selection of cementing materials and the component composition of the cementing solution for lining the bottom-hole zone is carried out taking into account the geological and technological parameters of the formation around the production wells depending on the temperature of the formation and the composition of formation waters.
4. To prepare lightweight cement mortars for supporting the bottom-hole zone of wells, it is proposed to use low-density additives. It is economically beneficial to use products and waste from domestic industry, which can significantly reduce the density of conventional cement stone. The resulting cement stone created on this basis is almost two times lighter than cement stone obtained on a cement-water basis.
5. Due to the use of such reagents as chamotte, expanded clay, carbonate, and bran in cement, cement savings of up to 25–30 % are possible.
6. Lightweight cement mortars are prepared for use at high temperatures and are able to move a greater distance in the drainage zone of the well, compared to mortars prepared on a standard cement-water base, which allows to cement better deep production wells.
7. A number of regulatory documents (program, methodology and technological regulations) have been developed, agreed upon, approved and tested, which reflect the principles of justifying the choice of cement composition based on the geological and technological parameters of the formation and conducting analyzes according to API standards.

Scientific Petroleum
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Reservoir and petroleum engineering

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