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Analysis of cement stone in a well and a modern strategy for choosing grouting systems

Analiza kamienia cementowego w otworze wiertniczym oraz nowoczesna strategia doboru systemów cementacyjnych

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ABSTRACT: The long road of development of cementing technology, which ensured the development of cement compositions, methods of preparation, chemical treatment and transportation of binder material into the annular space of the well, did not solve all the problems of high-quality isolation of the layers. A reasonable physical criterion and exact methods for assessing the quality of fastening have not been found either as it is very difficult to reproduce downhole conditions during experimental work in order to establish a large number of simultaneously acting factors on the durability of the borehole lining. In this regard, there is no generally accepted method for testing cementing materials in the world and the issue of the necessary strength of stone from various cementing materials intended for cementing columns and installing cement bridges has not been resolved. The world's leading drilling service companies (Schlumberger, Halliburton, etc.) do not use special cements such as UCG, OCG, etc., but prepare their mixture specifically for each cementing process, based on one base cement selected for these oil and gas fields. Various types of weighting agents, lighteners and other mixing additives with the base cement provide the well-specific grouting system. All over the world, these systems are being prepared at specially equipped bases. The conducted studies give grounds to assert that high-quality normal, lightweight and weighted cement mortars can be obtained on the basis of local raw materials, provided that modern technology and equipment are available.

Key words: casing, cementing, calculation, drilling, pipe deformation, coefficient, Karadag region.

STRESZCZENIE: Długa droga rozwoju technologii cementowania, która zapewniła opracowanie składów cementu, metod jego przygotowania, obróbki chemicznej i transportu materiału wiążącego do przestrzeni pierścieniowej odwiertu, nie rozwiązała wszystkich problemów związanych z wysokiej jakości izolacją warstw. Podczas prac eksperymentalnych bardzo trudno jest odtworzyć warunki panujące w otworze wiertniczym, aby można było ustalić i przebadać szereg działających równocześnie czynników, mających wpływ na trwałość warstwy rur okładzinowych w otworze. W związku z tym na świecie nie ma ogólnie przyjętej metody testowania materiałów cementowych, a kwestia niezbędnej wytrzymałości kamienia z różnych materiałów cementowych przeznaczonych do cementowania kolumn rur okładzinowych i instalowania mostów i korków cementowych w odwiercie nie została rozwiązana. Wiodące na świecie firmy świadczące usługi wiertnicze (Schlumberger, Halliburton itp.) nie stosują specjalnych cementów, takich jak UCG, OCG itp., lecz przygotowują swoją mieszankę specjalnie do każdego procesu cementowania, bazując na jednym rodzaju cementu wybranym dla tych konkretnych złóż ropy i gazu. Różne rodzaje środków obciążających i innych dodatków mieszanych z cementem bazowym zapewniają stosowanie specyficznego dla danego złoża systemu cementowania. Na całym świecie systemy te są przygotowywane w specjalnie wyposażonych bazach. Przeprowadzone badania dają podstawę do stwierdzenia, że wysokiej jakości normalne, lekkie i obciążone zaczyny cementowe można uzyskać na bazie lokalnych surowców – pod warunkiem dostępności nowoczesnej technologii i sprzętu.

Słowa kluczowe: rurowanie, cementowanie, obliczenia, wiercenie, deformacja rury, współczynnik, rejon Karadag.

Introduction

Improving the quality and efficiency of production work, protecting the subsoil, flora and fauna of the surrounding area, as well as the successful implementation of plans for the development of the oil and gas industry largely depend on the quality of isolation of the exposed reservoirs and the provision of well support. The stability of the well walls and the durability of the isolation of the formations exposed during drilling is achieved by fixing the wellbore with casing strings,

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followed by cementing the annulus and annular space. The long road of development of cementing technology, which ensured the development of cement compositions, methods of preparation, chemical treatment and transportation of binder material into the annular space of the well, did not solve all the problems of high-quality isolation of the layers (Nelson and Guillot, 2006). A reasonable physical criterion and exact methods for assessing the quality of fastening have not been found either. It is very difficult to reproduce downhole conditions during experimental work in order to establish a large number of simultaneously acting factors on the durability of the borehole lining. In this regard, there is no globally accepted methodology (APJ Specification 10A, 1991; Dowell Schlumberger Publication, 1997; Halliburton Services, 2004; Cementing Product Catalog, 2006) for testing cementing materials and the issue of the required strength of stone from various cementing materials intended for cementing columns and installing cement bridges has not been resolved. Currently, of the two links artificially introduced into a drilled well in the pipe-cement ring-rock system, only casing pipes are subjected to careful and reasonable calculation. The cement ring of a well, a complex hydraulic structure that performs many functions, is practically not calculated, although its influence is taken into account by a certain, insufficiently substantiated coefficient when calculating casing strings.

Research materials and methods

The need to cement wells with high temperatures and pressures, aggressive environments, an increase in the difference between pressures in the productive horizon and aquifers, the implementation of an artificial (chemical or thermal) impact on the exploited horizons in order to increase oil recovery, the use of grouting cements and compositions of various physical and mechanical characteristics require a new approach to the issue of their choice, taking into account not only the above factors, but also the rheological characteristics of the layers being drilled and the cement stone itself.

Based on experimental and field data (Bulatov, 1990) it was found that lightweight cements used in well cementing have the shortest service life. In this regard, it is of great interest to use a lightweight polymer-cement composition (Halliburton Services, 2004) for well casing, suitable for use up to a temperature of 1000°C. After the load is removed, there is no residual deformation, which ensures long-term durability of the well lining.

In the process of drilling a well, for various reasons, it is necessary to install cement bridges: moving away from the tool left in the well, correcting the curvature of the wellbore, eliminating mud loss, testing the overlying formation, etc. Despite the apparent simplicity of the process, of all the works associated with cementing wells, the installation of cement bridges accounts for the largest number of unsuccessful operations. With increasing drilling depth, the probability of installing high-quality bridges decreases. This is due to the fact that at present they are installed mainly through the open end of the drill string, i.e. without the use of any devices, which leads to the mixing of drilling and cement slurries and obtaining a poor-quality bridge due to the low physical and mechanical characteristics of the formed stone. Often, for this reason, it is not possible to obtain bridges from the first installation, which leads to significant additional costs. Method b. VNIIKrnefti for calculating the cement bridge, taking into account the mixing of cement and drilling slurries, which generally improves their quality, still plans to spend an additional amount of cement, reagents and other additives. In this regard, it is much more efficient to develop and use special devices that improve the quality of cement bridges being installed and ensure that operations are carried out under control.

The working conditions of the cement ring of the well lining were studied by domestic and foreign scientists, in whose works attempts were made to unambiguously justify the necessary strength of the cement stone, as well as to develop requirements for backfill materials. At the same time, in view of the difficulty of taking into account all the conditions under the influence of which the cement stone is formed in the annular space, these works mainly reflect the effect on the cement ring as the most potent factors – temperature and pressure (Bulatov, 1990; Dowell Schlumberger Publication, 1997). When evaluating the strength of the cement shell, it is necessary to take into account the type of its stress state. As is known, the cement sheath experiences a three-dimensional stress state, while there is an opinion that the strength of a cement stone formed in a complex stress state is 20% higher than in uniaxial compression (Gaivoronsky, 1969). Izmailov (1963) assumed that the cement ring of the annular space of the well experiences a linear stress state and therefore, only the interaction forces on the strength of the stone are taken into account. And although this does not fully reflect the actual working conditions of the cement shell, it is of interest to conclude that the strength of the cement stone, as well as, obviously, the thickness of the cement ring are of great importance for ensuring reliable fastening of an oil and gas well. The cement sheath, as a link in the well casing system, experiences loads associated with those that act on the casing string. In this regard, the idea of using high-strength cements to partially unload the casing string and using thin-walled pipes looks very tempting. Studies of the work of casing pipes with a cement ring in the well are given in the works of Izmailov

(1966) and Guseinov et al. (1967). Izmailov (1966) on the basis of experimental data noted that a low-strength cement ring does not contribute to an increase in the stability of casing pipes; well an increase in the mechanical strength of the cement stone lead to a significant increase in the stability of the column-cement ring system; the creation of a cement sheath with a high modulus of elasticity will significantly increase the bearing capacity of pipes. In the second work (Guseinov et al., 1967), on the basis of experimental data, the situation differs in that the presence of a cement sheath unloads casing pipes by 15–20%.

In the above works and in the studies of other authors, calculation formulas are given that make it possible to determine the ultimate loads perceived by the cement stone for the accepted stress state of the cement ring.

From the point of view of the correct choice of well design and provision of the necessary clearances between the lowered casing string and rocks, it is of practical interest to determine the required thickness of the cement sheath at a given (calculated) value of the ultimate load. A calculation method and a theoretical substantiation of the strength of the cement shell is given in the Ishchenko's work (1977). Ishchenko and Selvashchuk (1977) noted that in the case of using round casing pipes, the tensile strength of the cement stone should be limited to 5–9 MPa, and in the case of oval pipes – 10–18 MPa, because exceeding these values does not lead to a significant increase in the resistance of casing pipes to collapse by external pressure. Depending on the parameters of the casing pipes and the above compressive strength of the cement stone, the required thickness of the cement sheath is set:

$$\delta c = (0.14 - 0.26)\ R \text{ at } C = 0$$

$$\text{and } \delta c = (0.29 - 0.44)\ R \text{ at } C = 0.0215$$

where R is the well radius, C is the ovality factor and δc is the thickness of the cement stone.

Theoretical studies of the effect of the cement sheath on the stability of casing pipes (Peslyak, 1973) gave grounds to their author to assert that the cement stone prevents pipe deformation. The effect of three loads on the cement ring independently of each other is considered:

- change in fluid pressure inside the column;
- pressure of rocks and non-filtering liquid on the outer surface of the cement ring;
- change in the pressure of the liquid filtering in the cement stone.

Based on the calculation scheme (Peslyak, 1973) it is shown that the cement ring supports the pipes and partially unloads them; in the case of the use of strong cement, the working conditions of the pipe are greatly facilitated. For weak cement, the pressure of the filtering liquid is transferred to the pipe almost completely, decreasing by only 2–3%; in the case of strong cement, where only 80% of the total pressure is transferred to the pipe; for thinner-walled pipes, this value will decrease even more.

The above works, complementing each other, reflect the stress state of the cement ring and consider the work of the cement stone in the elastic region. At the same time, the structure of the stone and its possible changes under the influence of loads, as well as the properties of individual cements, are not considered. A wide variety of oil well cements, mixtures currently used, and various conditions for cement stone hardening, complicate the possibility of using the elasticity modulus E for calculating the unloading coefficient, obtained only for stone from oil well cement, hardened at room temperature and atmospheric pressure, and ultimately these introduce an error in calculations. The modulus of elasticity and the pore structure of stone from various oil-well cements were studied with the determination of the value of the empirical coefficients of dependencies E on porosity for multi-phase structures (Danyushevsky and Dzhabarov, 1978). A method for calculating the modulus of elasticity of various cement compositions without carrying out experiments is proposed, and the need to determine it for each type of cement is noted. However, for all the importance of the conclusions made, the determination of E without taking into account real well conditions will also lead to errors in the calculations. The authors of the above works consider the cement ring capable of unloading the casing string, but in the work of Mochernyuk (1972) analyzing the technical and economic feasibility of using high-strength grouting materials for cementing oil and gas wells, the feasibility of using cements of high strength grades is denied. The autor stated that the forces do not act on the cement stone located in the annulus under the conditions of volumetric compression (Mochernyuk, 1972). Under these conditions, as noted in the work, the strength of the cement stone is an indefinite concept. However, a statement of this kind does not quite correctly reflect the process of the formation and operation of cement stone. The well is a complex structure in which the cement sheath is under the action of various loads from both the wellbore and the formation – stops and starts of pumps, characterizing the pulsating nature of the action of the drilling fluid column, tripping operations with shock loads, tool rotation, and the effect of reservoir pressure, which is also variable. In addition, the cement sheath plays the role of a structure that carries axial loads, which are created due to the weight of the casing string during their suspension and in the process of drilling out cement glasses. Stresses act on the stone during perforation in the process of well development, as well as when the liquid level in the well decreases. The stresses on the cement ring also change during operation. Finding the cement ring in a state of variable multiaxial tension is obvious (Peslyak, 1973; Ishchenko, 1977).

There are a number of works by Bulatov (1976, 1990) and in these it is noted that the qualitative separation of productive horizons can be fully ensured by the use of cement, which gives a stone with a tensile strength of 1.5 MPa in bending or 5.0 MPa in compression, i.e. in essence, the need for the use of strong cements is denied. At the same time, the author considers it more important to obtain an impenetrable, non-shrinking stone with low water loss and good adhesion to pipes and rocks. Simultaneously it is noted that an increase in the mechanical strength and elasticity modulus of cement stone will lead to some increase in the bearing capacity of casing pipes (Bulatov, 1976). Therefore, in some cases, in the absence of a choice of pipes and the possibility of increasing the bearing capacity of casing pipes in specific conditions, this measure deserves attention.

Most researchers tend to believe that the cement stone is a low-permeable body, but nevertheless, the loads through it on the casing string are transmitted instantly. More accurate would probably be the opinion that the stresses on the casing string are transmitted not only instantly, but also over time. This is due to the possible fluidity (creep) of the rocks that make up the walls of the well, natural and artificial thermal stresses, changes in loads under various modes of development and operation of the wells. This premise gives grounds to assert that the cement stone works in more difficult conditions and it is not surprising that researchers are interested in studying the rheological characteristics of cement stone under the action of various loads, taking into account the time factor. Attempts were made to clarify the unloading coefficient of cement stone and the feasibility of taking it into account in the calculation of casing pipes.

A brief review of the above works shows that the problems of cementing, including the assessment of the role of cement stone, have not been practically resolved, since there is no consensus on this issue. Without a unified methodology for conducting work, researchers come to conflicting conclusions. Almost all researchers in their calculations take the characteristics of the stone at the time of loading, which does not reflect the true state of affairs, since the well is a long-term hydraulic structure designed for a long period of operation.

At the same time, the need for a time factor in ongoing research is noted (Rakhimbaev and Karimov, 1978). Accounting for the time factor is necessary to clarify and determine the coefficient of unloading of the cement sheath and to improve the calculation of casing strings.

The presence of a wide variety of grouting materials requires the solution of the issue of their preferred use in specific conditions of column cementing (Nelson and Guillot, 2006).

Since the well is designed for a long period of work, it follows the need to substantiate the real criteria for assessing the quality of the well casing. It is likely that an initial quality assessment immediately after cementing and a second one after the expiration of the design life of the cement sheath is necessary. At the same time, this period can be taken year in less than the life of the well. The installation of quality cement bridges also requires solving this problem. Obviously, it is necessary to substantiate the strength standards of cement stone and develop technical means that allow the installation of high-quality cement bridges.

The modern strategy for choosing cementing systems is as follows.

All special cements were supplied to Azerbaijan, and even in relatively good times, the oil and gas industry of Azerbaijan experienced a shortage of almost all brands of cements available in the nomenclature in the former USSR. Moreover, it should be noted that the range of cement grades for various conditions. The USSR was very narrow compared to other countries. Drilling of oil and gas wells in the areas of the Azerbaijan State Oil Company is carried out in a wide range of depths, under conditions of abnormal formation pressures, requiring the use of cement slurries with a density of less than 1.40 to 2.4 g/cm^3, in the presence of bottomhole temperatures from 200°C to 1500°C. These conditions, with the danger of absorption, fluid manifestation, the need to lift the cement slurry to a great height, the presence of nearby oil and water facilities, etc., create certain difficulties in carrying out plugging operations.

We note only some disadvantages of cements produced in the former USSR: there are no cements from which solutions are obtained with a density of less than 1.38 g/cm^3, 1.50–1.80 g/cm^3, 1.85–2.00 g/cm^3, or more than 2.25 g/cm^3; lightweight and weighted cements such as OCG and UCG have low stone strength, and the strength of the cement stone, laid down in the technical conditions for the production of these cements, is underestimated, so it was possible to slightly exceed this deliberately underestimated strength to produce OCG and UCG cements of the highest quality category. The low strength of the cement stone reduces the durability of the lining, and affects the further deepening of the well (griffin, losses, manifestations, etc.) and development and operation of the well (breakthrough of alien waters, collapse and withdrawal of the column, plug formation, impossibility of developing a productive object, etc.). In addition, these cements are unstable (large water sedimentation, etc.), while OCG has a high water loss and extended setting time, and UCG-1 and UCG-2 cements practically do not provide their maximum density, i.e. respectively 2.15 g/cm^3 and 2.30 g/cm^3, providing actually 2.10 g/cm^3 and 2.25 g/cm^3. After the collapse of the USSR, the supply of special cements to Azerbaijan (OTsG, UCG-1, UCG-2, SCHPTsS-120, etc.) became very complicated; it must be noted, however, that even before. The collapse of the USSR, these supplies were not stable. Our Republic has all the necessary raw materials (limestone, marl, barite, magnetite, pumice, quartz sand, shell, clay, drywall, ash, etc.), production facilities (Karadag cement plant, Karadag plant of weighting agents, etc.) and labour resources to create our own base for obtaining lightweight, pozzolannous, weighted and other types of cements.

In Azerbaijan, there are industrial deposits of all the components necessary for the preparation of the types of cements needed by oilmen:

- limestone – Gobustan, Karadag regions, Shuvelyan, Kala, Shahbulag of Aghdam region, etc.;
- clay – Gobustan, Ramanin, Sumgait, Dash-Salakhli, Karachukhur, Uchtepa, Khanlar and others;
- barite – Shamkhor, Khanlar, etc.;
- magnetite – Dashkesan;
- gypsum – Khanlarsky, Alyatsky, etc.;
- drywall (gypsum) – Tauzskaya, Ganja, Kazi-Magamedskaya, etc.;
- quartz sand – Mardakan, Shuvelyan, Sabunchu, etc.;
- pumice – Lachinskaya and others;
- volcanic ash – Jeyranbatansky, Kazakh, Dzhabrailsky, etc.

The world's leading (APJ Specification 10A, 1991; Dowell Schlumberger Publication, 1997; Halliburton Services, 2004) drilling service companies (Schlumberger, Halliburton, etc.) do not use special cements such as UCG, OCG, etc., but prepare their own mixture specifically for each cementing process, based on one base cement selected for these oil and gas fields.

Various types of weighting agents, lighteners and other mixing additives with the base cement provide the well-specific grouting system. All over the world, these systems are being prepared at specially equipped bases.

In Azerbaijan, in the Karadag region, near the village Primorsk, on the seashore, such a Schlumberger base was built, where with the help of air compressors, bulk dry materials, in containers (barite – 400 tons, bentonite – 60 tons, cement – 180 tons, mixing reserve – 100 tons) and other equipment it is possible prepare any tamponage system. Ingredients must meet certain requirements – be dry, ground, etc. Tanks are weight batchers-mixers used in the pressure-vacuum system, designed to work as a vacuum tank and as a pressure tank. The tanks have air filters, aeration jets, a dust collector, a batcher-mixer, etc. Schlumberger (Dowell) prepared and then cemented all wells for all foreign companies in the sea and onshore. Mixtures were prepared on the basis of class G base cement according to API standards adopted for oil and gas fields in Azerbaijan (based on cementing conditions).

It is necessary to build a base of this type for SOCAR, for which all raw materials are available.

The conducted studies (Suleymanov, 2012a, 2012b, 2012c) give grounds to assert that high-quality normal, lightweight and weighted cement mortars can be obtained on the basis of local raw materials, provided that modern technology and equipment are available.

For example, in principle, lightening additives such as Dzhabrail ash (density – 2.6 g/ cm^3) or Karadag shtyb (density 2.6 g/cm^3) with good grinding can be a lightening additive, but when used in a non-ground form, weighting agents, which results in a very necessary and scarce density of Portland cement mortar of 1.85–2.00 g/cm^3, tk. above a density of 2.00 g/cm^3 can be obtained with conventional weighting agents such as barite, etc.

The chemical composition of the ash is as follows:

- SiO_2 – 64.2%;
- Al_2O_3 – 18.25%;
- Fe_2O_3 – 3.05%;
- CaO – 3.87%;
- MgO – 1.57%;
- SO_3 – 0.4%;
- $Na_2O + K_2O$ – 6.7%.

Cement-ash slurry has increased sedimentation stability and structural strength at an early stage of the structure formation, which is very important when there are dangers of fluid intrusion into the wells. While, for example, cement-sand mixtures of this type are aggregatively less stable than pure cement.

The complete chemical analysis of the sludge is as follows:

- SiO_2 – 5.2;
- Al_2O_3 – 1.0;
- Fe_2O_3 – 0.3;
- CaO – 50.05;
- MgO – 0.4;
- SO_3 – 0.7;
- p.p.p. – 40.76%.

In order to improve the quality of cementing, and clay deposits, representing 70–80% of the well section in Azerbaijan, as well as other properties, there is a cement-slurry.

Conclusion

1. Cement-stud mortar has less water loss, less contraction and exothermic effects, less shrinkage of cement stone, and better sedimentation resistance than pure Portland cement mortar.
2. Khanlar gypsum and Ganja, Tauz gypsum are almost the same. Dashkesan magnetite has a density of 4.30–4.50 g/cm^3, and the weighting agent from the magnetite concentrate of the Dashkesan concentrator contains 55–57% iron.

3. Thus, having built this base, the oil industry of Azerbaijan will receive all varieties of the necessary backfill systems, with densities from 1.48 to 2.41 g/cm^3.

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