Nafta-Gaz 2024, no. 3, pp. 167–171, DOI: 10.18668/NG.2024.03.05

Buffer fluid and method of its preparation for plugback cementing

Ciecz buforowa i metoda jej przygotowania w celu wykonania korków cementowych

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ABSTRACT: The study of extensive material on the results of well cementing in various regions of the world shows that the quality of plugging operations is largely determined by the degree of displacement of the drilling fluid from the well. No one has ever specifically developed a buffer fluid for plugback cementing. When carrying out reverse cementing, determining the end time of the cementing process is of great importance, which largely depends on the choice of buffer fluid. The purpose of this work is to give the buffer fluid the properties of a magnetic locking element during plugback cementing of casing strings while increasing its separating ability. To achieve this, carboxymethyl cellulose is additionally dissolved in water before the displacement of the components when preparing a buffer liquid. Rubber crumbs are then mixed with the filler, and mixing is carried out under a pressure of at least 0.2 MPa. The buffer liquid contains the following components in the following wt.% ratios: carboxymethylcellulose 4–5, crumb rubber 7–8, ferromagnetic metal powder 15–16, with the remaining portion being water. The buffer fluid of the optimal composition not only maintains no less (than 98%) displacing power, but also exhibits an exceptionally low filler fall rate (when diluted by half). Furthermore, it does not linger in a pipe with an open end and an annular magnet inside, preventing settling plugs. The economic benefits of using a buffer fluid primarily stems from ensuring reliable control over the filling of the annular space with cement slurry, preventing its pumping from the annulus to the intracasing space, and preventing clogging of the productive underlying formation with cement.

Key words: buffer fluid, plugback cementing, drilling fluid displacement, carboxymethyl cellulose, crumb rubber, ferromagnetic metal powder.

STRESZCZENIE: Badanie obszernego materiału na temat wyników cementowania odwiertów w różnych regionach świata pokazuje, że jakość operacji cementowania w dużej mierze zależy od stopnia wyparcia płuczki wiertniczej z odwiertu. Jak dotąd nie opracowano cieczy buforowej przeznaczonej specjalnie do wykonywania korków cementowych. Podczas cementowania odwrotnego bardzo ważne jest określenie czasu zakończenia procesu cementowania, co w dużej mierze zależy od wyboru cieczy buforowej. Celem niniejszej pracy jest nadanie cieczy buforowej właściwości magnetycznego elementu blokującego podczas wykonywania korków cementowych rur okładzinowych przy jednoczesnym zwiększeniu jej zdolności separacyjnych. W tym celu, podczas przygotowywania cieczy buforowej, karboksymetyloceluloza jest dodatkowo rozpuszczana w wodzie przed wyparciem składników. Granulat gumowy następnie jest mieszany z wypełniaczem, przy czym mieszanie odbywa się pod ciśnieniem wynoszącym co najmniej 0,2 MPa. Ciecz buforowa zawiera następujące składniki w następujących proporcjach wagowych (%): karboksymetyloceluloza 4–5, granulat gumowy 7–8, proszek metalu ferromagnetycznego 15–16, a pozostałą część stanowi woda. Ponadto nie zalega w rurze z otwartym końcem i pierścieniowym magnesem wewnątrz, zapobiegając tworzeniu się korka. Korzyści ekonomiczne wynikające ze stosowania cieczy buforowej wynikają przede wszystkim z zapewnienia niezawodnej kontroli nad wypełnianiem przestrzeni pierścieniowej zaczynem cementowym, zapobiegania jego pompowaniu z przestrzeni pierścieniowej do przestrzeni wewnątrz rur okładzinowych oraz zapobiegania kolmatacji produktywnej formacji podziemnej cementem.

Słowa kluczowe: ciecz buforowa, wykonywanie korków cementowych, wypieranie płuczki, karboksymetyloceluloza, granulat gumowy, proszek metalu ferromagnetycznego.

Introduction

Buffer fluids are liquids or slurries that are pumped into the well prior to the pumping of the cement slurry during primary casing cementing, cement bridge installation, or remedial work. Compressed air, gases, and foams are also used as buffers.

The significance of buffer liquids in the technological process of cementing oil and gas wells is substantial.

The experience gained in separating productive horizons in regions such as Azerbaijan, Tataria, Bashkiria, and in a number of other regions of the former USSR indicates that injecting a buffer fluid before the cement slurry can reduce the percentage of unsuccessful cementing.

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Article contributed to the Editor: 08.11.2024. Approved for publication: 16.02.2024.

Buffer fluids find widespread use globally, including in the USA, UK, Romania, Hungary, etc. Analyzing the impact of a buffer fluid on well cementing success in the USA revealed a 30% increase in the number of successfully cemented wells when a buffer fluid was used, compared to cases where it was not used for any reason.

However, in a number of cases, the injection of a buffer fluid resulted in emergency situations, leading to increased pressure when forcing the cement slurry into the annulus beyond calculated values. The poor performance of buffer fluids is linked to unsuccessful cementing in numerous oil and gas areas.

Bulatov et al. (1999) cite cases of poor-quality cementing at the Gazlinskoye field, resulting in four wells flowing openly with the formation of craters exceeding 100 m in depth. In other instances, gas shows were observed during the WOC period and after cementing. According to the trust Kharburneftegaz, out of 130 wells at the Shebelinskoye field, annulus pressures were observed in 115 wells.

In the Novo-Zaprudnenskaya area of the Kuibyshevneftegazrazvedka trust, repair and isolation work was required during the development of almost every second well drilled for Devonian deposits due to the ingress of water from the D2 formation into the D1 formation.

The costs of eliminating the consequences of unsuccessful cementing in the oil and gas region of Mangyshlak are substantial. Only in one area of Kurganbay, three out of five casing strings were poorly cemented. At the Dunginskoye oil field, in almost every well it is not possible to raise the cement slurry to the design levels. Unfavorable situations regarding cementing quality are also prevalent in other exploration areas, where annular manifestations, leaving a large amount of cement slurry in pipes, under-lifting of mixtures to the required heights are quite frequent phenomena (Bakhtin et al., 1993).

Methodology

The study of extensive material on the results of well cementing in various regions of the near and far abroad shows that the quality of plugging operations is largely determined by the degree of displacement of the drilling fluid from the well.

Based on experimental and industrial studies, it can be concluded that buffer liquids can serve various functions:

- to prevent the growth of structural viscosity and dynamic shear stress of the boundary layers of the buffer with cement slurry and flushing fluid;
- to erode the oil slick and loose part of the mud cake from the well walls and improve the adhesive properties of clay rocks and the remaining dense part of the mud cake with plugging stone;
- to displace drilling fluid from the annulus;
- to reduce hydraulic pressure when pumping displacement fluid;
- to regulate the temperature in the wellbore;
- to eliminate places of absorption of washing liquids and grouting slurries.

At the Pravdinskoye oil field, eight wells were cemented using buffer solutions with plugging properties (RTS) proposed by the Tatar oil industry. These solutions include cement-bentonite mixture (3:1), CMC (4%), and soda ash (2% by weight of the cement mixture). The water-mixture ratio is selected based on the spreadability of the suspension of 22 cm along the AzNII cone. Simultaneously, the resulting suspension has a density of 1.30–1.33 g/cm^3, water loss of 4 cm^3, and the formed stone acquires a strength of 0.5 MPa after 5 days.

However, studies have shown that suspensions with increased viscosity are formed at the boundary of the buffer fluid with the drilling fluid. For example, when 5% drilling fluid with $\gamma = 1.18$ g/cm^3, $T = 25$ s, $B = 8.5$ cm^3/30 min enters the RTS, the spreadability decreased to 18 cm; 14.5 cm. With the introduction of 30% of the same solution, the suspension becomes difficult to pump.

Aqueous solutions of $CaCl_2$, NaCl, $MgCl_2$ can be used as buffer liquids only when isolating halogen deposits, when plugging and flushing liquids are saturated with the corresponding salts. Calcium chloride is a strong accelerator of the setting time of cement slurries. Therefore, incomplete displacement of the $CaCl_2$-enriched buffer fluid may lead to premature setting of the cement slurry in the annulus.

The hydrocarbon buffer fluid also failed the test. After pumping the calculated amount of cement-bentonite and cement slurries into the well, pumping of the displacement fluid was started. However, already at the initial moment of squeezing, the layers were ruptured and 21 m^3 of liquid was pumped without circulation.

Acoustic logging was carried out after 3 months. The downtime of the well prior to completion showed no contact between the casing string and the cement sheath, even in the near-wellbore zone. Satisfactory adhesion is noted only in the places where the lantern is installed.

To determine the cause of the increase in pressure, the following experiment was carried out in the laboratory. 10% diesel fuel was added to the cement-bentonite slurry with a density of 1.55 g/cm^3, the mixture was placed in the glass of the KTs-3 consistometer, and the stirrer was turned on with a blade rotation speed of 60 rpm. After 45 min. of stirring at a temperature of 70°C and $p = 35.0$ MPa, the solution acquired a non-fluid state.

Field tests of oil as a buffer fluid also ended unsuccessfully. During cementing, the pressure in the process of drilling through the solution increased by 4 MPa against the calculated one.

Studies conducted by American scientists (Sutton et al., 2014) on a Fann viscometer showed that when less than 50% of a hydrocarbon liquid is added to a cement slurry, the structural viscosity increases sharply. A further increase in the dosage of the hydrocarbon liquid (over 50%) dilutes the suspension.

Experimental part

Analyzing the results of the use of oil-based buffer fluids, it can be concluded that their use in cementing wells drilled using non-oil-based fluids is feasible.

The buffer fluid is designed under the condition of obtaining a locking element during plugback cementing of wells, provided there is a magnetic device in the annular space at the lower end of the casing string, above the through holes in it. Blocking occurs by mixing and diluting the buffer fluid with a carrier fluid diluent directly by hydrodynamic mixing in the flow, induced by changing the hydraulic injection mode when the buffer approaches the magnetic device. Subsequently, the pumping is stopped, causing the metal powder and rubber crumb to precipitate from the buffer. The mixture, having lost its bearing capacity, is captured by a magnet, over which a settling plug is formed, which is almost impossible to push through.

In order to effectively implement carrier fluid dilution by changing the hydraulic injection mode directly within the fluid flow in the annulus, CMC was used as the carrier fluid. It dissolves quickly and well in water, which is very important due to the limited time available for mixing during the movement along the annular space. Moreover, CMC possesses high bearing capacity and forms a spatial structure with crumb rubber due to good permeability. This ensures that the buffer fluid serves its purpose as a separator fluid for drilling and cement slurries, enabling timely dilution of the buffer fluid directly in the flow until it loses its bearing capacity, precipitates a solid phase and forms an impenetrable sediment column above the bypass holes in the column during plugback cementing.

Other known fluids used as carrier fluids are unsuitable in this case (Bulatov, 2011; Halliburton, 2014; Weatherford, 2017). For instance, drilling mud cannot carry more than 6–8% of the solid phase (filler), whereas in this composition, 22–23% (wt.) of the solid phase is present; gipan is very sensitive to polyvalent ions and does not allow the presence of calcium ions; polyacrylamide is long and difficult to dissolve in water at 40–50°C with stirring for 48 hours, while other reagents are expensive and scarce (Schlumberger, 2015; Ferry and Romien 2019; Schlumberger Dowell 2019; Bittleoton and Guillot, 2021).

Therefore, CMC is the most suitable choice for achieving the goal. The selected quantitative content range of CMC (4–5 wt.%) is determined by the fact that the lower limit (4 wt.%) is sufficient for the formation of an anti-sedimentary structure, and the content of the upper limit makes the buffer liquid non-fluid.

In addition, at 75–80°C, i.e. temperature at the bottomhole of medium-deep wells for which the buffer fluid is intended, the content of CMC allows, with effective dilution of the carrier fluid, to quickly achieve a loss of its bearing capacity. With a short stop, an impenetrable plug of sedimentation forms in the annular space above the lower holes in the column wall and is securely fixed by the wellhead pressure gauge, indicating a sharp increase in pressure (a “stop” signal). This prevents the transfer of cement slurry from the annulus to the inside of the casing.

The rubber crumb in the composition performs several functions: it is well wetted by the CMC solution, forming a strong anti-sedimentation structure. Additionally, it as an elastic filler, contributing to a more complete replacement of the drilling fluid in the well with cement and acts as a carrier of ferromagnetic metal powder. With the usual addition of metal powder, it begins to sink even in a very viscous buffer liquid, as the density of the metal (7.8 g/cm^3) is 6–7 times higher than the density of the carrier liquid. Therefore, to prepare the buffer liquid, it is preferable to use a ferromagnetic metal powder with sharp edges, such as waste from grinding steel parts, or a separated metal powder from a magnetic ore, the particles of which also have sharp edges.

The particle size of ferromagnetic metal powder is from 0.1 to 0.5 mm, and the particle size of crumb rubber is 2–3 mm. Before being introduced into the carrier liquid, rubber crumb is dry mixed with metal powder, and mixing is alternated with a load on the mixture of at least 0.2 MPa. This causes the sharp and smaller particles of the metal powder to pierce the surface of the larger elastic particles of the crumb rubber, covering the surface of the crumb rubber with particles of the ferromagnetic metal powder. As a result, the total density of one such “conglomerate” is about 3.1–3.3 g/cm^3, which is more than half the density of the metal. Accordingly, the buoyancy of the filler in the carrier liquid is also higher. Further, with the subsequent dilution of the carrier liquid, not only does the metal powder precipitate, but also a mixture of metal powder with rubber as a whole. This mixture has the property of being attracted to a permanent magnet and forming a plug. The deposition plug growing from above is obtained at the desired height with a relatively small metal consumption. Instead of a “conglomerate”, it is possible to use a conventional weighting agent such as magnetite and hematite.

Considering the necessity for establishing a mechanical bond between sharp metal particles and rubber crumb particles, with an adequate quantity of both crumb and metal powder for this purpose, as well as accounting for their sedimentation stability in the carrier liquid, the specified amounts are 7–8 wt.% for rubber crumb and 15–16 wt.% for metal powder. Water imparts fluidity to the buffer fluid and is a diluent for the carrier fluid.

Thus, along with the function of the buffer fluid itself, this buffer fluid has gained the ability to reliably lock the hydraulic communication channel during plugback cementing of casing strings.

In a borehole, a spacer fluid is used in plugback cementing. A casing string is lowered into the well with through holes in the string wall at its lower end (finished filter) and a permanent annular magnet on the outer surface of the casing string installed above the holes. A buffer fluid is pumped into the annular space, and water is pumped into the space above and below the buffer fluid. Water is a diluent of the carrier fluid, and its amount is selected based on the condition of loss of carrying capacity of the carrier fluid when they are fully intermixed. Then, a cement slurry is pumped in, which replaces the drilling fluid in the annular space, displacing it into the casing space through holes in the casing wall located below the permanent magnet. In this case, the displacement is carried out in a hydraulic mode close to the piston one. When the buffer liquid begins to approach the magnet, they switch to the hydraulic mode, which ensures the most complete and rapid intermixing of water with the buffer liquid. For example, a developed laminar regime of liquid flow in the annular space is used for this, in which an intense "lingual" interpenetration of liquids occurs. After that, the injection is stopped and rubber crumb with metal powder intensively precipitate from the buffer liquid, which has lost its bearing capacity as a result of dilution with water. The settling particles are captured by the magnetic field and block the annular space, then all subsequent layers of filler deposition are deposited on them. As a result, a plug is formed in the annular space, when cement slurry pumping resumes, the pressure at the wellhead increases strongly, which indicates the end of the casing string cementing process.

For comparative testing, five samples of the buffer liquid with different contents of components, including limit values, out-of-limit values and intra-limit values, are prepared, and a sample of a known buffer liquid of optimal composition is tested.

The following characteristics of the buffer fluid were studied: spreadability along the AzNII cone, cm; the degree of substitution of drilling mud in a vertical pipe at a displacement velocity of 1 m/s; the rate of sedimentation of the filler at 75°C after diluting the carrier fluid by half; limiting pressure gradient during extrusion of the settled filler from the tube.

Research results

When studying the degree of substitution of a buffer liquid for drilling mud in a vertical pipe, a pipe with a length of

Table 1. Comparative testing of buffer fluids
Tabela 1. Testy porównawcze cieczy buforowych

N/N	Composition		The content in the composition of the buffer liquid [wt.%]				Characteristics of the buffer liquid				Retention by the magnetic field during the deposition of the filler
			CMC	rubber crumb	ferromagnetic metal powder	water	spreading-bridge on cone AzNII [cm]	degree of substitution of a buffer liquid for a drilling mud in a vertical pipe [%]	settling rate of the filler when the carrier liquid is diluted twice with water [m/s]	limiting shear gradient when the settled filler is squeezed out of the pipe [MPa/m]	
1	suggested	1	3.0	6.0	14.0	77.0	26	97	0.300	0.35	delayed completely
2	suggested	2	4.0	7.0	15.0	74.0	24	98	0.280	0.38	delayed completely
3	suggested	3	4,5	7,5	15,5	72.5	21	98	0.240	0.39	delayed completely
4	suggested	4	5.0	8.0	16.0	71.0	19	98	0.210	0.40	delayed completely
5	suggested	5	6.0	9.0	17.0	68.0	14	99	0.090	0.36	delayed completely
6	famous*	6					16	98	0.012	filler accumulation in the pipe does not occur	does not linger

* Buffer liquid contains [wt.%]: bentonite clay – 14, crumb rubber – 11, granular adsorbent – 24, water – 51

2 m and an internal diameter of 15 mm is used. The limiting extrusion gradient of the settled filler is studied in a tube with an internal diameter of 50 mm and a length of 0.5 m. At the lower end inside the tube, a ring magnet with a diameter of 50 mm and a central hole of 25 mm is rigidly mounted, with a magnetization of about 1 tl.

The load is periodically applied on the mixture during the mixing process with a hand roller, and the load value is set using a hand dynamometer. The optimal load is 0.2–0.3 MPa.

As a ferromagnetic metal powder with sharp particles, metalworking-grinding waste of steel parts is used, as well as metal powder separated by a magnetic field (permanent magnet) from ground magnetic ore (magnetite). The particle size of the ferromagnetic metal powder is from 0.1 to 0.5 mm. Rubber waste is used as crumb rubber. The particle size of crumb rubber is 2–3 mm.

At 22.0°C (room temperature) the composition has sedimentation stability, fluidity along the AzNII cone 20–25 cm, displacement capacity approaching 100%.

The compositions of the buffer liquids and the results of their comparative tests at 75°C are shown in Table 1.

The optimal composition must satisfy the following conditions: be sufficiently fluid (with a fluidity of more than 18 cm along the AzNII cone); the degree of replacement of the drilling mud by the buffer liquid should be close to 100; the buffer fluid should lose its bearing capacity when diluted with water by half, while the settling rate should be as high as possible, so the settling of the filler occurs during the temporary cessation of cement slurry injection into the annulus, and the stop time should be minimal; drop-out filler should be delayed by the magnetic field of a permanent ring magnet installed on the outer surface in the lower part of the casing above the through holes in the wall of the casing; the settled filler plug must have a sufficiently high shear limit gradient to provide a reliable stop signal for the completion of cement slurry pumping.

As can be seen from Table 1 of comparative tests, the proposed buffer fluid is the most acceptable (2–4), since it has good spreadability over the AzNII cone (15–24) cm, a high degree of substitution of the drilling mud (98%), and a high rate of filler settling (from 0.21 to 0.29) m/s, has a sufficiently high limiting shear gradient (0.35–0.40) MPa/m, which, with a filler column height in the annulus of 15–20 m, gives a noticeable “stop signal” 5–8 MPa.

Conclusions

The optimal composition of the buffer fluid (wt.%) is CMC 4–5, rubber crumb 7–8, ferromagnetic metal powder 15–16, with the remaining part being water 74–71. Other buffer fluid formulations are unacceptable: formulation 1 has almost no increase in filler fall rate (when diluted) compared to formulation 2, and formulation 5 is non-flowable (non-pumpable).

The buffer fluid of the optimal composition (composition 6) has no less displacing power than 98%, but it has a very low rate of fall of the filler (when diluted by half), which, moreover, does not linger in a pipe with an open end and an annular magnet inside and does not form settling plugs.

The economic effect of the use of a buffer fluid consists mainly of ensuring reliable control over the filling of the annular space with cement slurry, preventing its pumping from the annulus to the intracasing space, and preventing clogging of the productive underlying formation with cement.

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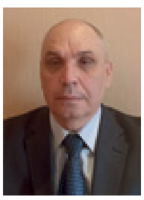

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