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RESEARCH ARTICLE

DEVELOPMENT OF A HYDROCARBON BUFFER FLUID SYSTEM AND ITS FIELD TESTING

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ABSTRACT

In the process of drilling wells when attached with a hydrocarbon-based drilling fluid, the ability of this solution to form high-viscosity non-fluid mixtures in the mixing zone occurs when interacting with a water-based grouting solution and leads to poor-quality cementing. In order to remove the crust-film of hydrocarbon from the walls of the borehole and casing with washing, as well as high-quality cementing, a system of oil-based spacer fluid (OBSF) has been developed. It is pumped into the well before the cement mortar in order to separate the drilling and cement mortar from each other and displace the hydrocarbon solution from the cemented interval, as well as to completely eliminate the formation of coagulation in the displacement zone of the hydrocarbon and cement mortar. The use of a buffer fluid of the OBSF leads to an increase in the quality of cementing, a reduction in the time spent on the selection of formulations before cementing and the elimination of losses of significant volumes of grouting and drilling fluids.

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INTRODUCTION

During drilling of wellbores using oil-based drilling mud (OBM), generally some problems related to well casing occur. These problems emerge due to the ability of OBM and water-based cement slurry to form high-viscosity unflowable blends in the mixing zone, thereby complicating well casing resulting in poor-quality cementing. The problem is expressed in pressure increase during squeeze cementing which causes hydraulic fracturing of a reservoir and low cement top (i.e. cement slurry fails to fill the annulus to the intended level) [2]. There is a method of cementing a casing string in a wellbore drilled using oil-based drilling mud. The method comprises running the casing column and its washing, pumping into the casing of spacer fluid and water-based cement slurry, installation of a bottom plug, squeezing spacer fluid and cement slurry to the casing annulus, stopping squeezing and subsequent waiting on cement (WOC) period. The method is implemented by using the three-portion spacer fluid: 1- diesel fuel; 2-water solution containing 0.5% dissolvan, 1% sulfonol and 12% sodium carbonate; 3- water solution containing 1.5% hydrolyzed polyacrylonitrile and 3% sodium carbonate [1]. The disadvantage of this method is low quality of cementing due to presence of the mixing zones of spacer fluid and OBM, use of multi-component compositions, and large consumption of diesel fuel.

There is another method of cementing a casing string in a wellbore drilled using OBM: the following three-portion spacer fluid is applied: 1 – diesel fuel with the addition of emulsifier (non-ionic SAA) - emultal; 2 – 7.5% hydrochloric acid solution; 3 – technical water with the addition of emulsifier – dissolvan (non-ionic SAA) [1]. The disadvantage of this method is low quality of cementing due to the presence of the mixing zones of spacer fluid and OBM, large consumption of diesel fuel. One more method similar to the technical base and achieved results is cementing a casing string using the following three-portion spacer fluid: first portion – diesel fuel + 0.5% - 2% non-ionic SAA (dissolvan, sulfonol, OP-10); second portion – water + 0.5% - 2% non-ionic SAA; third portion - water used to prepare cement slurry [3]. The disadvantage of this method is low quality of cementing due to lack of efficiency of such spacer fluid, presence of the mixing zones of spacer fluid and OBM, failure to provide sufficient removal of OBM by the space fluid, and low washing capacity of the spacer fluid. All mentioned methods when using chemically active and multi-component substances complicate the cementing technology. When removing OBM, water from the cement slurry cannot remove hydrocarbon film crust from the walls of a wellbore and a casing string resulting in low cohesion of hydrated cement or its absence, which causes cross flows of reservoir fluids into the casing string annulus. For the purpose of washing and removal of hydrocarbon film crust from the walls of a wellbore and a casing string, as well as to perform qualitative cementing, an oil-based spacer fluids system was developed (OBSF).

This spacer fluid type is injected into a wellbore before cementing operation to separate drilling mud and cement slurry, and to remove OBM from the cemented spacing, as well as to completely exclude coagulation in the mixing zone of OBM and the cement slurry. The indicated purpose is achieved by implementing a method of cementing of a casing string in a wellbore drilled using OBM, where OBSF (oil-based spacer fluid) system is applied to separate OBM and cement slurry. The method also includes running casing column and its washing, pumping into the casing string of spacer fluid and water-based cement slurry, installation of a bottom plug, squeezing spacer fluid and cement slurry to the casing annulus, stopping squeezing and subsequent waiting on cement (WOC) period. The oil-based spacer fluid consists of two pumped compositions:

- The first composition of the spacer fluid is intended for wetting of hydrocarbon film crust on the walls of a wellbore and a casing string, as well as to prevent coagulation in the mixing zone of spacer fluid and OBM.
- The second composition, pumped after the first one, is intended for washing out hydrocarbon film crust and prevention of coagulation in the mixing zone of spacer fluid and OBM. For preparation of spacer fluid, commercial products are used (diesel fuel and sulfonol).

Based on the results of laboratory studies, if the content of sulfonol in the spacer fluid is 4%, its wetting capacity is being lowered. 5% content of sulfonol is unreasonable as its properties remain virtually the same. If the content of sulfonol in the second composition of the spacer fluid is less than 10%, its washing capacity is lowered. 12% content is unreasonable as its properties remain virtually the same. Combination of components, strengthening of washing out effect and increase of the OBM volume removed by water-based cement slurry, increase of the separating capacity of the spacer fluid in the mixing zone of OBM and water-based cement slurry are unobvious. Suggested technical solution also matches the criterion of “industrial applicability” as the declared oil-based spacer fluids system can be put into practice in construction of oil and gas wells. OBSF system successfully passed the test in installation of cement plugs and cementing of casing columns at the oil fields of Western Turkmenistan.

The test was performed at well № 147 of North Goturdepe field. The depth of 324mm casing column is 2700m. Drilling was performed by 295,3mm drilling bit to the depth of 4112m with transition to 215,9mm pilot drill bit to the depth of 4400m for the purpose of exact localization of productive oil reservoirs. Drilling of the wellbore using OBM was performed from the depth of 3800m, with the application of Versadril system, which consists of oil phase (80%) and water phase (20%) with the density of 1.45 g/cm^3.

The task of the test was as follows:

- Installation of 215,9mm cement plug in wellbore in the spacing of 4400-4250m with the length of 150m.
- Cementing of the first section of 244,5mm casing column in the spacing of 4140-4250m with the length of 150m.
- Cementing of the second section of 244,5mm casing column in the spacing of 0-2600m.
- Installation of the cement plug was performed in the spacing of 4400-4250m to cover the pilot wellbore with the smaller diameter of 215,9mm, and preparation to run 244,5mm casing column.
- Downhole reservoir conditions were the following: temperature: +93°, pressure: 645 kgf/cm^2, required thickening time of the cement slurry is 3 hours 30 minutes.
- Cementing of the first section of 244,5mm casing column in the spacing of 4140-2600m was performed to cover 295.3mm open part of the bore for operation of productive reservoirs.
- Downhole reservoir conditions were the following: temperature: +93°, pressure: 645 kgf/cm^2, required thickening time of the cement slurry is 4 hours.
- Cementing of the second section of 244,5mm casing column in the spacing of 0-2600m was performed to cover 324mm cased borehole section with outflow of the cement slurry to the surface and setting up the equipment of the wellhead.

Downhole reservoir conditions were the following: temperature: +72°, pressure: 455 kgf/cm^2, required thickening time of the cement slurry is 3 hours 30 minutes. Portland cement PCT I-G-SS-1 (well cement, production of Kelete cement plant) was used as binding material, chemical agent ferro-chromelignosulfonate was used as properties regulator of cement slurries, sodium dichromate ($Na_2Cr_2O_7$) and foam suppressant PAV XT-48 were used as temperature regulator. Seawater was used as a base for grouting fluid. OBSF was used to displace OBM by cement slurry, exclude coagulations in their mixing zones, wash out hydrocarbon film crusts from the walls of the wellbore and casing string. Impact of OBSF on the properties of drilling muds and cement slurries in the mixing zones is shown in Table. Impact of OBSF on the properties of drilling muds and cement slurries in the mixing zones to install a cement plug in Ø215,9mm wellbore in the spacing of 4400-4250 m in cementing of Ø 245mm casing column at the depth of 4140 m at well № 147 of North Goturdepe field. Installation of the cement plug in 215,9 mm wellbore in the spacing of 4400-4250m, WOC is 48 hours, trip of 5t drilling equipment with washing and unloading on the cement plug at the depth of 4250m, air test by solution with density of 1.45 g/cm^3 at the pressure of 75 atm. - pressure-tight.

Installation of the cement plug in 215,9mm wellbore was performed without any repeatable operation. In cementing of 244,5mm casing column of the first section in the spacing of 4140-2600m and the second section in the spacing of 0-2600m, WOC was 48 hours. The casing column was pressurized with drilling mud with the density of 1.45g/cm^3 $P_{compressed}$ = 312 atm. and with seawater with the density of 1,02 g/cm^{3,} $P_{compressed}$ = 480 atm. - pressure-tight. The field test of OBSF performed at well №147 of North Goturdepe field was successful. The presented OBSF system was used on a massive scale on the oil and gas fields of Western Turkmenistan. For example:

- in cementing of 193,7mm shank adaptor lowered to the depth of 6197-6537 m at well №7 of Uzynada field;
- - in cementing of 245mm conductor lowered to the depth of 600m at wells № 1768, 1769 of East Goturdepe field.
- in installation of a cement plug on a two-combined production string with a diameter 139,7 x 168,3 mm at the depth of 3361-3726 m at well № 18 of South Gamyshlyja field;
- in cementing of the first and second sections of 244,5 mm technical column lowered to the depth of 4450m at well № 204 of North Goturdepe field;
- in cementing of combined productive string 177,8 x 139,7mm lowered to the depth of 6870 m at well №7 of Uzynada field and number of other wells.

Due to successful execution of the field tests, the OBSF system was patented by its author and registered under № 605 on 16.06.2013 in the National intellectual property service of the Ministry of economy and development of Turkmenistan. In order to remove the crust-film of hydrocarbon from the walls of the borehole and casing with washing, as well as high-quality cementing, a system of OBSF has been developed. It is pumped into the well before the cement mortar in order to separate the drilling and cement mortar from each other and displace the hydrocarbon solution from the cemented interval, as well as to completely eliminate the formation of coagulation in the displacement zone of the hydrocarbon and cement mortar [1, 2]. Industrial testing of the OBSF for displacement of a hydrocarbon-based solution was carried out at well № 7 of Uzynada field during cementing of the production column Ø178x139mm in the range 3935-6870m from 04.21.2017. OBSF is a special fluid that washes out the hydrocarbon crust from the walls of the borehole and casing, pumped before the grouting solution in order to displace the hydrocarbon-based drilling mud from the cementing interval and separation of drilling and grouting solutions to exclude coagulation phenomena in the mixing zone. When drilling a well on a hydrocarbon-based solution, difficulties arise associated with cementing the well. These difficulties are caused by coagulation in the mixing zone of

Table 1. Impact of OBS F on the properties of drilling muds and cement slurries in the mixing zones

Compositions	Properties of the mixture											
	24°C						90 °C					
	ρ, g/cm³	RV, s	φ° 300	φ° 600	η_{res} cPs	τ_0 dPa	ρ, g/cm³	RV, s	φ° 300	φ° 600	η_{res} cPs	τ_0 dPa
1	2	3	4	5	6	7	8	9	10	11	12	13
Spacer fluid № 1	0,92	19	18	29	11	21	0,88	16	7	10	3	12
Spacer fluid № 2	1,04	16	0	3	0	0	0,98	11	0	1	0	0
Spacer fluid № 1 - 50% + №2-50%	0,99	15	4	8	4	0	0,94	12	1	3	2	0
Drilling mud	1,45	43	50	93	43	21	1,43	24	23	40	17	18
Drilling mud - 50%, Spacer fluid № 1 - 50%	1,18	40	40	73	33	21	1,08	26	17	32	15	6
Drilling mud - 50%	1,24	384	195	>300	not changed	not changed	1,19	611	196	286	90	318
Spacer fluid № 2 - 50%												
Drilling mud - 50%	1,18	65	66	119	53	39	1,13	38	34	59	25	27
Spacer fluid (№1-25% + №2-25%)-50%												
Cement slurry	1,75	42	67	89	22	135	-	-	-	-	-	-
Cement slurry - 50%	1,35	20	18	35	17	3	Slurry delaminated to fluid , hydrocarbon and solid phases					
Spacer fluid № 1 - 50%												
Cement slurry - 50%	1,4	16	9	16	7	6	1,38	14	6	11	5	3
Spacer fluid № 2 - 50%												
Cement slurry - 50%	1,36	18	13	23	10	9	1,34	17	8	15	7	3
Spacer fluid (№1-25% + №2-25%)-50%												

water-based buffer fluid and hydrocarbon-based drilling mud. In this regard, there is an increase in viscosity to a state of non-fluidity, forming a thick mass. This leads to an increase in pressure in the process of pushing through the solution and, as a result, to various complications such as hydraulic fracturing of layers, lack of access of the grouting solution to the design height, etc. Water cannot remove the hydrocarbon crust-film from the walls of the borehole and casing, which leads to weak adhesion of cement stone or its absence and causes overflows of reservoir fluids in the backwater space, etc. To prevent the above-mentioned complications when cementing the production column to displace the hydrocarbon-based drilling mud with grouting, it was decided to apply the composition of the hydrocarbon buffer fluid "OBSF". OBSF consists of 2 compositions of buffer fluid, each of which differs from each other in purpose and composition:

- 1st - designed to displace and prevent coagulation phenomena in the displacement zone with a hydrocarbon-based drilling fluid and wetting of the hydrocarbon crust-film on the walls of the borehole and column;
- 2nd - is designed to wash out the hydrocarbon crust-film from the walls of the borehole and column and prevent coagulation phenomena in the mixing zone with cement mortar [4].

At the same time, buffer fluid systems one and two together complement each other and enhance the leaching efficiency of the hydrocarbon crust-film from the walls of the borehole and casing. The tests were carried out at well № 7 of Uzynada field. The interval of the lowered production column is Ø178x139.7 mm at 3935-6870 m. Drilling of the well was carried out with a bit Ø215.9 mm to a depth of 6937 m and an eccentric bit Ø161.1mm (with a broadening of Ø190mm) to a design depth of 7150 m on a hydrocarbon-based solution. Parameters of the drilling mud before the descent of the production column: density p = 1.55g /cm^3; viscosity T = 47sec; water output W = 1.4 cm^3; thickness of the clay crust K = 0.5mm; static shear stress - for 10sec; Q_{10} = 11dPa, for 10 min. Q_{10} =16dPa; φ_{300} = 43; φ_{600} = 72; plastic viscosity $\eta_{res..}$ = 29sPz; dynamic shear stress τ_0 14dPa; electrical stability E_v =1172v; Phase composition – $V_{carb.ph}$ = 66%, $V_{water.ph.}$=12%, $V_{hard.ph}$ = 22%; TU = 41 °C. The ratio of the hydrocarbon phase (diesel fuel) to the water phase: D/W = 85/15. The cementing of the production column Ø178x139.7mm in the range of 3935-6870m was carried out in order to overlap the non-cased part of the borehole with a diameter of 215.9 mm for the operation of productive formations and repair work in the well. The downhole - formation conditions of the well were: temperature +109 °C, pressure 820 kgs/cm^2, the required thickening time of the grouting solution 3-30 hours. In accordance with the conditions and requirements of the cementing of the production column Ø178x139.7mm in the laboratory of the Institute "Nebitgazylmytaslama" and the department of fastening of oil and gas wells (UCNGS), formulations of grouting solutions were selected. Portland cement PCT 1-100 (Keletinsky Cement Plant Ave.) was used as a binder, a chemical reagent FHLC was used as a regulator of the properties of grouting solutions, a thermoregulator was sodium bichromate ($Na_2Cr_2O_7$) and a surfactant defoamer HT-48. The sealing fluids were prepared on seawater. To displace a hydrocarbon-based solution with a grouting solution, to exclude coagulation phenomena in the zone of their mixing, to have wetting and leaching of hydrocarbon crusts - films from the walls of the borehole and column, in order to ensure reliable contact of cement stone adhesion with the walls of the borehole and column, a OBSF with a volume of 5.0 m^3 was used.

The OBSF consists of 2 compositions:

OBSF 1 - V_1 = 2,0 m^3 – diz.fuel - 1,0 m^3

sulfonol - 0,2 m^3

Sea water - 0,8m^3

OBSF 2 - V_2= 3,0m^3 - Sea water-2,4m^3

sulfonol - 0,6m^3

Cementing of the production column Ø178x139.7mm in the range of 3935-6870 m, the time of the WOC was 48-00 hours. The issued conclusion on acoustic cementometry performed by the logging batch showed that there is a cement stone and adhesion in the concrete space of the well in the range 3935-6733 m. The column is pressed with drilling mud with a density of 1.55g/cm^3, $P_{pres.t.}$ = 560kgs/cm^2 - hermetically sealed.

CONCLUSION

- The use of the OBSF during the cementing of the production column Ø178x139.7mm in the range 3935-6870m at well №7of the Uzynada area with a grouting solution with a density of 1.80-1.85g /cm^3 ensured the formation of cement stone and its adhesion to the wall of the borehole and the column during the time of the WOC. Acoustic cementometry showed that there is a cement stone and adhesion in the well space in the intervals of 3935-6733 m at well № 7 Uzynada.

- Testing of the quality of cement stone in the column space Ø178x139.7mm was evaluated by crimping the column with drilling fluids with a density of 1.57g/cm^3 $P_{pres.t.}$ = 560 atm. - hermetically sealed.
- The use of the OBSF during the cementing of the production column Ø178x139.7mm allowed increasing the success of the operation. In this case, the grouting mixture is separated from the hydrocarbon-based drilling mud in all cases on both sides. The output of drilling mud to the surface of the wellhead with a lower density of 0.05-0.1 g/cm^3 or more allows us to judge the progress of cementing the casing string.
- Additional effect of use of the OBSF system is defined by strong fluxing impact on OBM and provides turbulent flow, thus creating effectiveness of washing out of hydrocarbon film crust from the walls of a wellbore and a casing string.
- The economic effect of use of the OBSF system is defined by increase of cementing quality, reduction of time for selection of compositions prior the cementing operation and exclusion of loss of large volumes of cement slurry and drilling fluids.
- Developed and presented OBSF system is different for its technology and simplicity of preparation in the field conditions using cheap materials.

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