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IMPROVING THE EFFICIENCY
OF CLEANING ANNULAR SPACE
WITH A NEW FLUSHING FLUID***

1. INTRODUCTION

The tightness on the contact of rock formation, hardened cement slurry and casing has a huge effect on the potential elimination of gas migration after casing columns are cemented. It depends, among others, on the efficiency of mud cake removal from the wellbore walls and displacement of mud (cleaning of the annular space) before cementing. Moreover, appropriate preparation of annular space before cementing, i.e. its flushing, contributes to the wellbore productive longevity and concurrent minimization of corrosion impact on the casing [3, 4, 6]. The problems associated with the cleaning of annular space cover such issues as rheology of drilling fluids, fluid mechanics (fluid flow in annular space), operation of chemical agents, surface active agents, surfactants and also chemical processes taking place in the course of hydration and bonding of cement slurry [1, 5, 10, 14].

The analysis of available literature [12, 13] reveals that despite the uninterrupted development of sealing techniques and technologies, inefficient cementing jobs still are the case. This urged the researchers to undertake works aimed at improving cleaning techniques applied in the annular space, and so work out a new recipe for the flush fluid.

Obviously flushing of casing columns is connected with correctly performed cementing job of particular casing columns, though this is only one of the elements of efficient sealing of the wellbore. The quality of sealing of annular space should be considered in terms of applied flush fluids. Attention should be also paid to the type of buffer fluid, cement slurry, and also effect of particular advancing fluids on the mud cake and drilled rock formation [8, 14, 15].

It is not possible to give one cause of inefficient sealing of the space between and beyond casing columns. Presently, we can only indicate groups of factors which may contribute to the formation of leaks and gas migration pathways These are, e.g. geological, technical, technological, mechanical or organizational factors (Fig. 1).
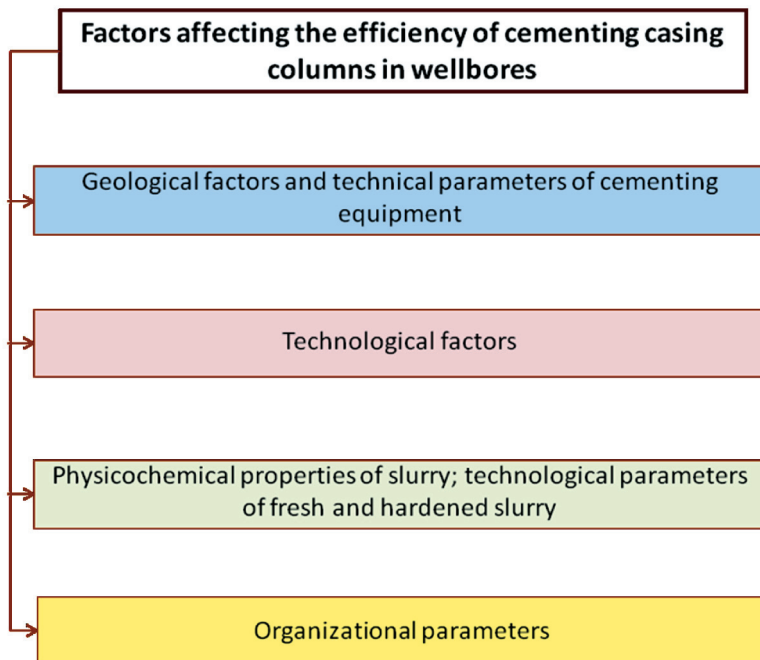
Factors affecting the efficiency of cementing casing columns in wellbores

Geological factors and technical parameters of cementing equipment

Technological factors

Physicochemical properties of slurry; technological parameters of fresh and hardened slurry

Organizational parameters

Fig. 1. Factors affecting the efficiency of cementing casing columns in wellbores

When the improvement of annular space cleaning is involved, i.e. procedure preceding cementing jobs, the main role is played by the group of technological parameters (Fig. 2).

At this stage the type, composition and performance of flush fluid used for cleaning the annular space are the most important factors [3, 4, 10].

Attention should be also paid to the type and parameters of muds used for drilling. They influence the characteristic of the generated cake, as well as composition and technological parameters of cement slurry used for sealing.
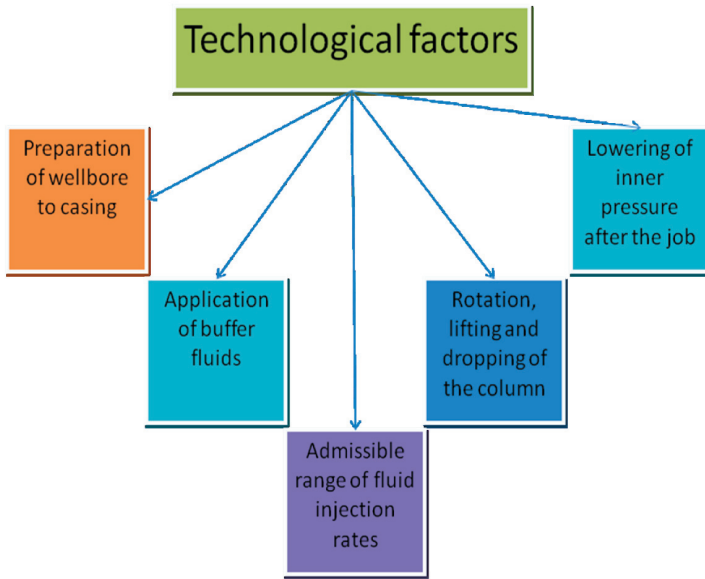
Fig. 2. Technological factors affecting the efficiency of cementing casing columns

After injecting the slurry to the annular space or beyond the casing, slurry contacts mud remains, favoring the generation of gas in a given interval. Therefore the annular space (or space beyond the casing) should be prepared and thoroughly cleaned before the planned cementing. Mud and its residues should be maximally removed. One of the methods of doing so is injecting appropriate amounts of flush or buffer fluids. Inappropriately exerted mud and badly removed cake remains may favor formation of gas canals on the hardened cement slurry/rock formation/casing contact (Fig. 3). This effect may appear mainly as a result of inefficient cleaning of the wellbore before the cementing job [6, 7, 10].
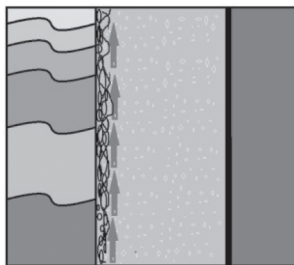

Fig. 3. Low degree of mud displacement and formation of gaseous canals

The analysis of the available literature [12, 13] reveals that sealing of a wellbore is conditioned by the type and composition of flush fluid, type and parameters of cement

slurry, applied mud and its inhibition properties [11, 14]. Particular fluids affect one another in the course of flushing, and mud displacement when performing cementing jobs. They also strongly affect the exposed rock and mud cake, which contains colloidal solid and polymeric particles. The quantitative and qualitative composition of mud cake in the wall has influence on the efficiency of sealing of the casing columns. Therefore it is very important to maximally clean the annular space before the cementing starts [7, 9, 14].

It should be emphasized that the quality of sealing significantly depends on the adhesiveness of cement slurry to the rock through the cake residue. The analysis of experiments shows that the tightness of the rock/hardened cement slurry contact depends on the density and consistency of the filter cake [2, 11, 13, 14]. The presence of mud sediment on the wellbore wall and on the casing is inversely proportional to the degree of washing out. Thick and dense cake can be removed by fluid, even by water or low--aggressive flush fluid injected at a proper flow regime. However hard cake may turn out irremovable in the same flushing conditions [14]. Therefore it is important to work out a proper kind of flush fluid which at certain flow regime may maximally remove the filter cake residue, and simultaneously wet the annular space, as this will contribute to better sealing of the cemented interval. Further in this paper authors discuss the results of research works on a new flush fluid which can most efficiently clean the annular space, and which can be used in lower concentrations as compared to the recently used ones.

2. RESEARCH WORKS

Research works on improving the efficiency of cleaning annular space with new flush fluid were performed by OGI-NRI and AGH-UST FDOG in compliance with standards [16, 17]: PN-EN 10426-2: 2006. *Oil and Gas Industry. Cements and materials for cementing wellbores. Part 2: Analysis of drilling cements* and API SPEC 10: *Specification for materials and testing for well cements*.

The laboratory tests were aimed at showing higher efficiency of new flush fluid as compared to the already used ones. The works were realized with a device built in OGI-NRI for pumping drilling fluids in a closed circuit (simulator of drilling mud flow, Figure 4, patent application INiG-PIB P.423842). Experiments were performed for selected flush fluids, which were pumped at the same rate and time of contact with the rock sample. Hydraulic parameters were selected during preliminary experiments when 11.2 l/min was assumed as optimum flow rate laboratory conditions, which corresponded to turbulent pumping and Reynolds number equal to about 3100. The assumed duration of contact of the fluid with the rock sample was 4 minutes. This resulted in the improvement of efficiency of cake removal. Although longer contact of the flush fluid with the removed filter cake could possibly result in higher efficiency of cake removal, none-

theless a 4 minute period was selected at this stage of experiments as only the efficiency of the flush fluid was in focus (no hydraulic parameters were accounted for).
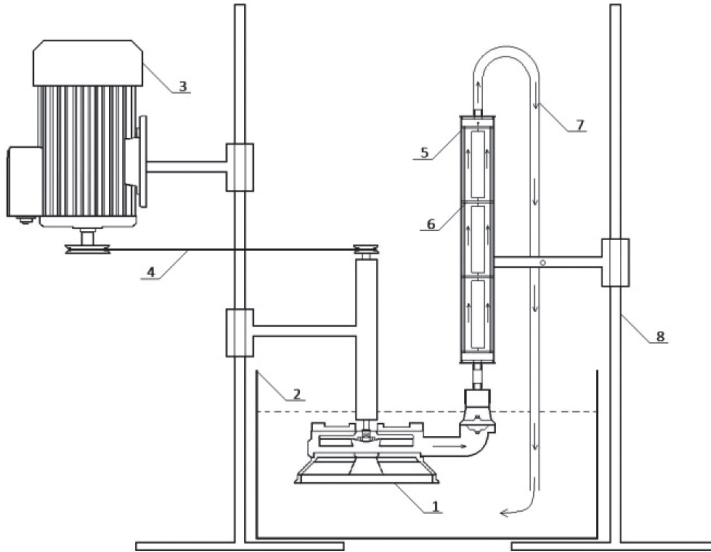

Fig. 4. Schematic of wellbore simulator of drilling fluid flow:
1 – Pump with rotor, 2 – Cup with drilling fluid, 3 – Motor, 4 – Pump drive,
5 – Tube with sample, 6 –Sample holder, 7 – Discharge tube, 8 – Device holder

For experiments sandstone was used. Cylinder-shaped cores of outer diameter 25 mm and length of 60 mm were cut out (photo – Fig. 5). The cores were mounted on a special holder (Fig. 6) inside a PVC tube (photo – Fig. 7), through which drilling fluids (mud and flush fluid) were pumped. This system could be used for simulating fluid flow in the annular space of a wellbore.

The experiments started with forming mud cake on the sandstone cores (Fig. 5). Mud was pumped into the simulated annular space and three cores in the holder were washed for 1 hr (photo – Fig. 8). The pumping mud rate was determined on the basis of preliminary tests and observations.

For obtaining cake, polymeric potassium mud containing contaminations from the drilled interval was used. The selection of this type pf mud (P-2K well) was dictated by the fact that mud's parameters favored the formation of hardly removable cake. After forming filter cake the cores were flushed for 4 minutes. The flush fluid was pumped at a rate of 11.2 l/min. The following flush fluids were selected:

– water (reference fluid),
– flush fluid used so far (1% MDC solution),
– new flush fluid.

Fig. 5. Core cut out of sandstone
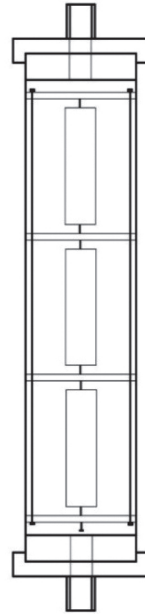

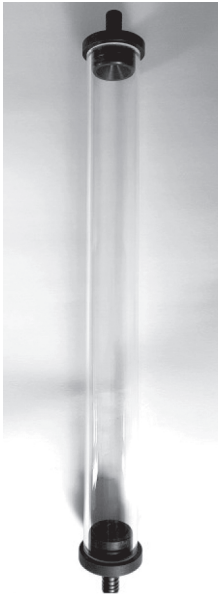**Fig. 6.** Cores with mud cake
(after flushing with mud)

Fig. 7. View of PVC tube with seals,
with disposed inlet and outlet of drilling fluid

Fig. 8. Schematic of sandstone cores
placed in a holder inside a PVC tube

The composition of the new flush fluid is the following:

– 0.2% alcohol ethoxylate – nonionic surface active agent,
– 0.2% alcohol ethoxylate – sodium sulfate, anionic surfactant from the group of alkyl ether sulfates.

A mixture of proper amounts of surface active agents and surfactant generated a synergic effect, which considerably reinforced the efficiency of the new flush fluid. Special attention was paid to an agent belonging to the group of surfactants (tensides) and a surface active agent. Chemically, every surfactant is a surface active agent, though not every surface active substance has features of a surfactant, e.g. ethanol. Figures from 9 to 11 show the efficiency of mud cake removal from a rock core sample when various flush fluids are applied.

Fig. 9. Flush fluid water   **Fig. 10.** Flush fluid 1% r-r MDC   **Fig. 11.** New flush fluid. Summaric concentration of agents 0.4% r-r

Duration of contact 4 min, pumping rate 11.2 l/min

The assumed methodics allowed for assessing the efficiency of cleaning of annular space based on the way in which mud cake was removed with the flush fluid. The efficiency of the flush fluid was defined by the adhesiveness on the hardened cement slurry/rock contact. For doing so, the sandstone cores with the mud cake on them were flushed with selected flush fluids, placed in a mold (photo – Fig. 12) and treated with cement slurry (photo – Fig. 13). After 48 hrs of hydration the adhesiveness on the hardened cement slurry/rock contact (cleaned of the cake) was measured. For analyzing the adhesiveness the sample were placed between two plates of a stiff testing machines (photo – Fig. 14) and the pull-off force was measured on the hardened cement slurry/rock contact under the load applied on the sample.

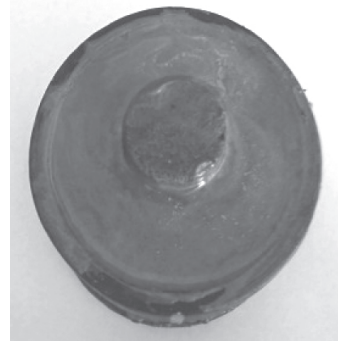**Fig. 12.** Core sample to be filled
with cement slurry

Fig. 13. Sample to undergo adhesiveness test
on the hardened cement slurry/rock contact

Fig. 14. Stiff testing machine

Adhesiveness (MPa) on the hardened cement slurry/rock contact was calculated with equation (1):

$$\sigma_p = \frac{P}{s} \cdot 10^{-3} \ [\text{MPa}] \tag{1}$$

where:

σ_p – adhesiveness on the hardened cement slurry/rock core contact [MPa],

P – force breaking the adhesiveness on the hardened cement slurry/rock contact [kN],

s – surface of rock sample/cement slurry contact [m²].

Force (P) was read out by the stiff testing machine and the surface of the rock/ hardened cement slurry contact equaled to the surface of core used for experiments and height of the cement slurry in the mold. The dimensions on the basis of which the hardened cement slurry/rock contact can be evaluated are given in Figure 15.

$$s = \pi \cdot d \cdot h \tag{2}$$

where:

d – diameter of core [m] during experiments equals to 25 mm = 0.025 m,

h – height of cemented part of the core during experiments equals to 44 mm = = 0.044 m.

$$s = \pi \cdot 0.025 \cdot 0.044 = 0.003456 \ [\text{m}^2] \tag{3}$$
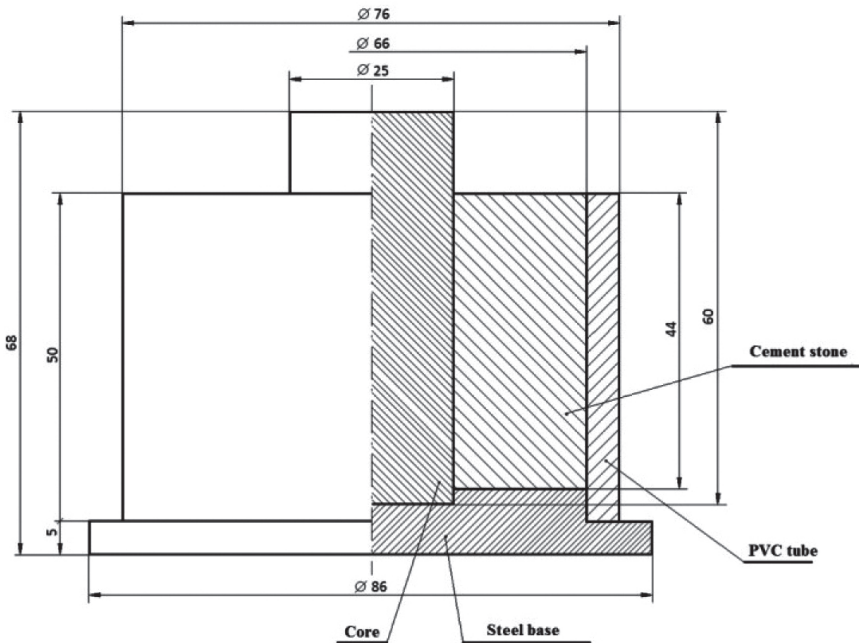

Fig. 15. Semi cross-section of mold with disposed core sample

Adhesiveness on the hardened cement slurry/rock contact σ_p was calculated with equation [4]:

$$\sigma_p = \frac{P}{0.003456} \cdot 10^{-3} = \frac{P}{3.456} \ [MPa] \tag{4}$$

Additional adhesiveness tests were performed for "clean" core, without any mud cake, and for a core with mud cake on it, except for the stage of cake removal. These values were used as reference point and defined as maximum and minimum basic adhesiveness values (Tab. 1). The obtained results were referred to these values. For obtaining reliable results all cores were covered with the same cement slurry, the composition and parameters of which are presented in Table 2. This cement slurry was applied for sealing casing columns at a temperature of about 25°C.

Table 1

Basic adhesiveness on hardened cement slurry/rock contact

	Pull-off force [kN]	Adhesiveness on hardened cement slurry/rock contact [MPa]
Maximum basic adhesiveness	8.2	**2.37**
Minimum basic adhesiveness	2.1	**0.61**

The adhesiveness on the hardened cement slurry/cleaned rock core contact obtained during experiments equaled to 1.01–1.24 MPa, whereas in the new flush fluid the cleaning of the annular space was improved and adhesiveness of 2.0 MPa. The comparison of the minimum basic adhesiveness of 0.61 MPa showed to an increase of adhesiveness from 66% (with water as flush fluid) to 103% (with flush fluid used so far).With the new flush fluid the increase of adhesiveness was of almost 230% as compared to the minimum value. The obtained results are listed in Table 3. The comparison of adhesiveness with maximum basic value of 2.37 MPa (Tabs 1 and 3) showed that the obtained results were lowered by 57% when water was used to 16% when new flush fluid was involved. The obtained values as compared to the maximum and minimum basic adhesiveness are listed in Table 3. The graphical interpretation of the improvement of a core sample cleaning with the applied flush fluid and comparison with maximum and minimum basic values are presented in Figure 16.

Table 2

Recipe and parameters of cement slurry used for adhesiveness tests
of the contact hardened cement slurry/rock during the test

Composition of slurry			Parameters of slurry				
			Density [g/cm^3]				1.78
Water		w/c=0.45	Spillability [mm]				240
Defoamer [%]		0.5	Water settlement [%]				0.0
Liquefier [%]		0.2	PVC viscosity [mPa·s]				91.5
Antifiltration agent [%]		0.2	Yield point [Pa]				6.48
Calcium chloride [%]		4.0	Structural strength [Pa]				2.88
Potassium chloride (bwow[1]) [%]		3.0	Filtration [cm^3/30 min]				36.0
Latex [%]		10.0	Densification time at temp. 25°C		Value 30 Bc [h:min]		2:55
Stabilizer of latex [%]		1.0			Value 100 Bc[2] [h:min]		3:32
Microcement [%]		10.0	Bonding time at temp. 20°C		beginning [h:min]		4:45
Cement CEM I 32.5R [%]		100			end [h:min]		5:35
Swelling agent [%]		0.3	Compressive strength after 48 hrs [MPa]		10.6		

Rheological parameters temp.: [20°C]	rpm	600	300	200	100	60	30	6	3	10"	10'
	readout in [j.f]	187	105	74	44	27	17	6	4	6	16

Quantities of all agents, except for potassium chloride are given in % proportion to cement content

[1] bwow – *by weight of water*

[2] Bc – unit of consistency of densification of cement slurry during measurement in a consistometer

Adhesiveness on hardened cement slurry/rock contact for selected flush fluids;
duration of fluid contact 4 min; flow rate 11.2 l/min

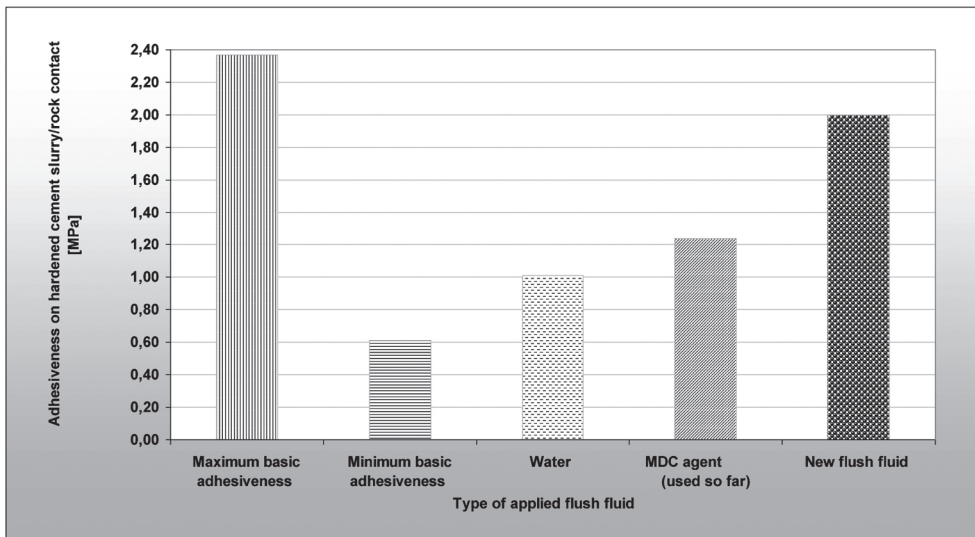| Type of agent used for making flush fluid	Pull-off force [kN]	Adhesiveness on the hardened cement slurry/rock contact [MPa]	% decrease of adhesiveness as compared to **maximum** basic adhesiveness	% increase of adhesiveness as compared to **minimum** basic adhesiveness
Maximum basic adhesiveness	8.2	2.37	–	–
Minimum basic adhesiveness	2.1	0.61	–	–
Water	3.5	1.01	↓ 57	↑ 66
MDC agent (applied so far)	4.3	1.24	↓ **48**	↑ **103**
New flush fluid	6.9	2.00	↓ **16**	↑ **229**

Fig. 16. Adhesiveness on the contact of hardened cement slurry/rock for various flush fluids
at injection rate 11.2 l/min; duration of contact with flush fluid 4 min

During experiments, mud cake was generated on a reference rock sample, then removed with various flush fluids, with water as reference fluid. The experiments were performed with the use of a simulator of drilling fluids flow, thanks to which the pumping

of fluid in borehole conditions could be transposed onto laboratory conditions. The improvement of efficiency of cleaning samples with one flush fluid, and so cleaning efficiency of these fluids, was determined on the basis of measurement of adhesiveness on the hardened cement slurry/cleaned rock core contact.

The analysis of the obtained results reveals that the new flush fluid considerably increases the adhesiveness on the hardened cement slurry/cleaned rock core contact, and so the higher efficiency of removal of mud cake from the rock formation. In the course of the experiments a new recipe of flush fluid was worked out. This fluid showed synergy of performance of the applied components. The new type of flush fluid allows for over 2-fold increase of adhesiveness in laboratory conditions as compared to the minimum basic value. Moreover only a 16% lowering of value was observed as compared to the maximum basic value. The new flush fluid was considered to best remove cake coming from polymeric-potassium mud.

The efficiency of performance of a given flush fluid will vary depending on the accumulating mud cake. The type of drilled rock formation, type and parameters of drilling mud and wellbore conditions (temperature and pressure) exert a considerable effect on the diversification of filter cake formed in the annular space. This necessitates individual selecting flush fluids in view of a given wellbore and its geological-technical conditions.

3. CONCLUSIONS

The following conclusions can be drawn from experiments on the improvement of cleaning efficiency in the annular space with new flush fluid:

1. Obtained results confirm that best efficiency of mud cake removal from polymeric-potassium mud was noted for the flush fluid, provided its components were used in a good proportion.
2. Upon using a mixture of surface active agents and surfactant, which perform synergically, mud cake can be better removed than with the traditional flush fluid.
3. Despite the fact that the summaric concentration of agents (0.4%) was lower than in the traditional fluid (1.0% MDC), better cleaning efficiency was obtained.
4. The new flush fluid allowed for over 2-fold increase of adhesiveness on the hardened cement slurry / rock contact.
5. Upon using new flush fluid only a 16% lowering of adhesiveness was obtained as compared to the maximum basic value (adhesiveness on the hardened cement slurry / rock contact).
6. Among all analyzed flush fluids, the new one was considered to most efficiently remove cake formed by polymeric-potassium mud.

Concluding, the analysis of the efficiency of mud cake removal conducted in laboratory conditions cannot ideally represent borehole conditions, and the worked out mud flow simulator allows for simulating semi wellbore conditions.

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