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EXPERIENCE OF MODERN COMPOSITE MATERIALS USAGE IN BOREHOLES CONSTRUCTION AT CROSS-BORDER REGION

1. Problem statement

During 19th-20th centuries in the Carpathians region several thousands of oil and gas wells were put into operation. Complex geological structure as well as long-term intensive operation of oil and gas deposits in Borislav - Pokutskaya zone of the Carpathians leads to changes in thermodynamical parameters of pools, rock deformation and, as a result, to crippling of the boreholes and creasing and damaging of boring casing. The above-mentioned actions not only complicate extraction of oil and gas but increase the technological charge on the environment [1]. As for example, at the Oriv - Ulichnyanske oil deposit 12 of 40 erected boreholes were dismantled because of creasing of casings. Geological and industrial information evidences that casing damage happens the most often when in the drill core there exist some formations predisposed to plastic deformations as well as when there is lack of reliable boring casing cementation. Borehole No. 4 of Lysovici, cemented by oil-well cement PCT-I-100, (Fig. 1) is a typical example of this.

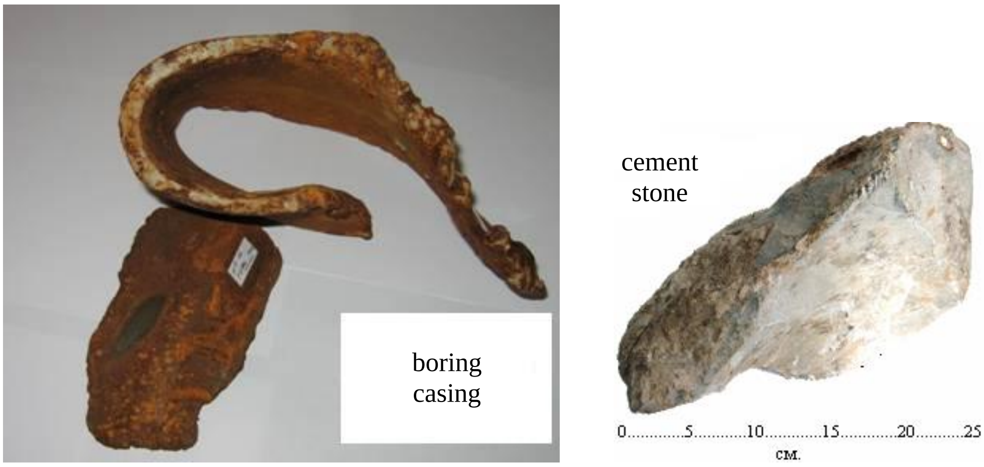

Fig. 1. Elements of damaged reinforcement of borehole No 4 of Lysovici

An especially important task is to provide the constructing reliability of the boreholes at the hydrocarbon deposits of Boryslavski, Dolinski and Nadvirnyanski oil industry regions which directly border such spa resorts as Truskavec, Skhidnycya Morshin and Bukovel and endanger the environment in cross-border region.

That is why the replacement of traditional Portland cement by the binders of new generation is utterly urgent.

2. Analysis of the latest investigations and publications

According to existing in Ukraine DSTU B V. (ДСТУ Б В.)2.7-88-99, the oil-well cements have been divided into three types: I - oil-well cement without additives, II - oil-well cement with mineral additives, III - oil-well cement with mineral additives, which regulate the density of the cement paste (grout). For cementation of intermediate and operating columns in most cases the cement ПЦТ (PCT) II-50 or ПЦТ (PCT) I-100 is used, which does not satisfy the up-to-day requirements for their technological properties such as: strength, corrosion resistance, rheological structure and deformation [2], what stipulates the necessity of their modification.

According to modern trends in building industry, the composition materials became a very wide alternative to traditional Portland cement, which is supported by many researchers. This trend corresponds to ideas of stable development and Kyoto Protocol.

In publication [3] the theory and the description of production technology of low power-consuming cement compositions through the physical-chemical modification by multifunctional organic and mineral additives for building industry needs were presented.

Considering the peculiarity of borehole casing of oil-and-gas deposits in Ukraine, and adhering to the innovation principle of “technological tandem” as the alternative to out-of-date and ineffective PCT II-50, PCT-100, the authors of the present publication developed composite oil-well mixes: TC-100 and TC-100 ПВ - for plugging the boreholes at moderate temperatures (51÷100°C).

Objective point: investigation of the use expediency of composition plugging materials at well construction in Pry-Carpathians oil-and-gas deposit.

3. Methods of investigation and materials

To implement the comparing investigations the cement stone formatted in the borehole No. 4 of Lysovici (Fig. 1), oil-well cement ПЦТ I-100 of JSC “Volyn-cement” and complex composite oil-well mixes TC-100, TC-100 ПВ of Ltd. “Helios”(Lviv) (Tab. 1).

TABLE 1

Comparing composition of materials

Type of material	Composition [%]									
	CaO	SiO_2	Fe_2O_3	Al_2O_3	SO_3	K_2O + Na_2O	MgO	TiO_2	CaO free	Other
PC- I-100 BAT “Volyn-cement”	66.39	21.3	3.5	5.25	0.91	0.86	0.71	0.18	–	0.9
TC-100 TC-100 ПВ	57.91	26.2	2.35	5.89	0.9	0.82	1.2	0.34	–	1.8

Investigations of technological properties were implemented in compliance with the requirements of ДСТУ Б В.2.7-88-99 “Oil-well cements. Methods of testing” СОУ 11.2-0013590: 2012 “Oil-and-gas boreholes. Order of cement receiving and holding, formulation elaborating and oil-well mortar preparing”.

Investigations of specimen microstructure and photographing of oil-well cement stone chips in different terms of hardening and microprobe x-ray analyses were implemented by raster electronic microscope РЕММА-102-02.

The quality of casing cementation was made by using the method of geophysical acoustics cement-bond logging (АКЦ) of serial device АКВ-1 and radial acoustic cement-bond logging RBT (Sondex).

4. Results of investigations

The cement stone specimen from the borehole No. 4 of Lysovici contains the smaller amount of CaO (instead of 64.9 only 44.6%), SiO_2 (instead of 20.75 only 16.21%) and Al_2O_3 (instead of 5.14 only 3.74%). In the same time concentration of BaO (16.8%) and SO_3 (13.2%) increased, what indicates the presence from 40 to 60% in the stone that is confirmed by microstructure investigations (Fig. 1). Cement stone formatted in such circumstances could not provide the necessary level of borehole casing reliability as an engineering construction.

It is stated that by their technological properties as ПЦТ-100 and composite mixes TC-100, TC-100 ПВ completely conform with the requirements ДСТУ Б В.2.7-88-99 for oil-well cements (Tab. 2). The stone formed from the cement ПЦТ-I-100 of JSC “Volyn-cement” (test specimen) is quite nonuniform and includes a big number of voids. Such structures are characterized by accelerated natural ageing [2]. The main reason of this is recrystallization of hydrated formations, in particular recreation of hexagonal hydroaluminates as for example C_4AH_{19}, into cubic C_3AH_6, as well as the coalescence of the tiny fibrous crystals into bigger ones. This results in creation of local areas of tension concentration in the stone volume. It is known that when the local tensions in some areas close to surfaces or in inter areas of the cement stone are higher than the ultimate strength of the correspondent monolith area, the fissure is created, which further acts as the new tension concentrator.

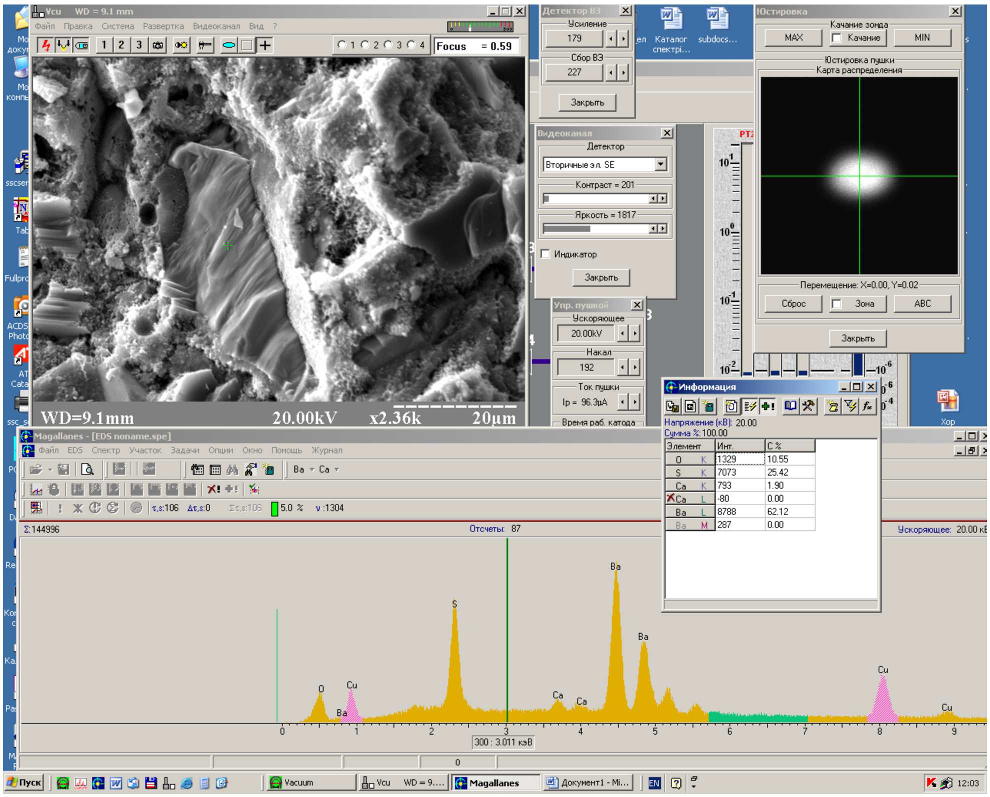

Fig. 2. Microstructure of cement stone from the borehole No. 4 of Lysovici

The formation character of crystalline structure of composite materials differs a bit from this in Portland cement and starts when the size of the solid phase nuclei, which appear on the coagulation stage of hardening, surpasses the critical point and depends directly on the chemical nature of hardening system phases, degree of solution supersaturated by hydrated formations and surface tension coefficient on the border of phase division. The velocity of crystallization grid creating is regulated by the diffusion coefficient of colloidal particles from supersaturated solutions of hydrate formations to solid phase nuclei. As the crystals of composite materials are different in their shape and elementary particle size, the structure linear defects (disparity dislocations and point defects-vacancies) are intensively created during their growing process. The crystals are growing perpendicularly to matrix surface in the direction to the most close particles of hydrated particles of the binder and serve as the centers of nucleation and crystallization on which later the hydration products are falling.

TABLE 2

Results of comparison tests of ПЦТ-I-100, TC-100 and TC-100 ПВ cements for their adequacy to requirements of ДСТУ БВ.2.7-88-99

No.	Name of indicator		Indicator value			
			According to ДСТУ	ПЦТ I-100	Composite materials	
					TC-100	TC-100 ПВ
1	Fineness of grinding - sieve residue on net No.008 according to ГОСТ 6613 [%], does not exceed		15	11.8	3.4	4.8
2	Cement density [g/cm^3]		–	–	–	–
3	Specific surface [m^2/kg], not less than		–	285	315	320
4	Cement suspension density [g/cm^3]		–	1.82	1.83	1.81
5	Water-mix relationship		–	0,5	0.47	0.46
6	Dehydration [ml], does not exceed		8.7	7.0	2.5	0
7	Cement grout spreadability [mm], not less than		200	195	230	200
8	Stiffening time up to 30 Berden units [min], not less than		90	90	90	>100
9	Solidification terms [hours-min]	beginning	–	1-30	1-15	2-00
		ending	–	2-10	1-35	2-15
10	Cement stone strength [MPa], not less than, after 1 day	at bending	3.5	4.5	6.1	5.7
		at squeezing	–	18.1	17.6	13.9
11	Stone fragility coefficient		–	4.02	2.89	2.44
12	Fluid loss [cm^3/30 min]		–	640	470	18.5
13	Rheological characteristics at 27°C according to FAN35 at 600 tpm 300 tpm 200 tpm 100 tpm 60 tpm 30 tpm		–	 120 80 55 40 35 20	 150 95 60 45 35 25	 170 105 90 70 55 45

Composite materials are characterized by evener distribution of hydrates in hydro silicate gel mass, better order of contact growth zones and increased number of merged fibrous in hydro silicate blocks. This provides formation of denser stone structure and locking of greater number of active centers of hydrate surface in contact interactions in comparison with the control specimen made from ПЦТ-I-100 cement what provides better strength (at bending) and deformation characteristics of cement stone made from composite materials.

Comparison tests of oil-well materials ПЦТ-I-100 and TC-100 during the cementation of intermediate casings at boreholes No. 201 and No. 202 Pivnichna Dolyna (Tab. 3) were implemented. To evaluate the intensity of works the SPC "Burenije" (Russia) [2] method was used. For this, after implementing the geophysical investigations, the value of quality coefficient *K* is calculated:

$$K = \frac{100\sum_{i=1}^{n}\lambda_1 + 200\sum_{i=1}^{n}\lambda_2 + 300\sum_{i=1}^{n}\lambda_3 + 400\sum_{i=1}^{n}\lambda_4}{L_ц}$$

where: $L_ц$ - the length of the cemented area [m]; $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ - the length of the cemented area: without the contact, at bad contact, at part contact and thorough contact, correspondingly [m]. Quality criteria: $K > 300$ - good quality; $K = 200$-300 - satisfactory quality; $K < 200$ - unsatisfactory quality.

From this data it is obvious that despite the more complex space shaft construction (increased bending of zenithal angle and shaft cavernosity) in the borehole No. 202 Pivnichna Dolyna the better quality of work is achieved ($K = 343.2$) according to the data of acoustic cement-bond logging just due to use of composite material TC-100.

TABLE 3

Comparison results of cementating of mediate boring casings

No.	Indicators	Borehole No. 201 Pivn. Dolyna	Borehole No. 202 Pivn. Dolyna
Cemantating conditions			
1	Cementing range [m]	0-2566	0-2433
2	Chisel diameter [mm]	295.3	295.3
3	Column diameter [mm]	219/245	219/245
4	Cavernosity coefficient	1.19	1.44
5	Maximum bending zenithal angle [degrees]	16	25
Drilling fluid			
6	Density [kg/m^3]	1510	1590
7	Relative viscosity, [s]	«dripping»	«dripping»
8	CH3 in 1 min and in 10 min [dPa]	>300	>300
9	Filtration indicator in 30 min [cm^3]	10	10
10	Thickness of filtration hack [mm]	3	3
Oil-well cement			
11	Type of oil-well mix	ПЦТ I-100	TC-100
12	Stone strength at bending [MPa]	4.7	5.1
13	Cementation quality coefficient	211.8	343.2

Considering the positive experience of composite materials TC-100 use during the casing of the borehole No. 202 Pivnichna Dolyna by mediate column and difficult geological conditions at producing lay opening for cementing the producing column it was recommended to use the stabilizing composite mix TC-100 ПВ with enhanced rheological and filtration properties. The diagram of thermobaric and technological conditions for testing the oil-well mortar TC-100 ПВ for cementing the first section 146×168 mm of operating column in the borehole No. 202 Pivnichna Dolyna is shown in the Figure 3.

Thermobaric conditions - dynamic temperature 63°C, pressure 42 MPa. Required pumping time - 3 hours. 20 min. Operational shutdown during the cementation - 60 min. On the basis of testing the formulation of oil-well mortar was selected (Tab. 4), which stipulates consecutive pumping into the borehole two portions of oil-well mix TC-100 ПВ with the density 1.81 and 1.88 g/cm^3 correspondingly. The results of geophysical investigations showed that the quality of cementation of operating column in 2462-3050 m is good (K_c = 384.1).

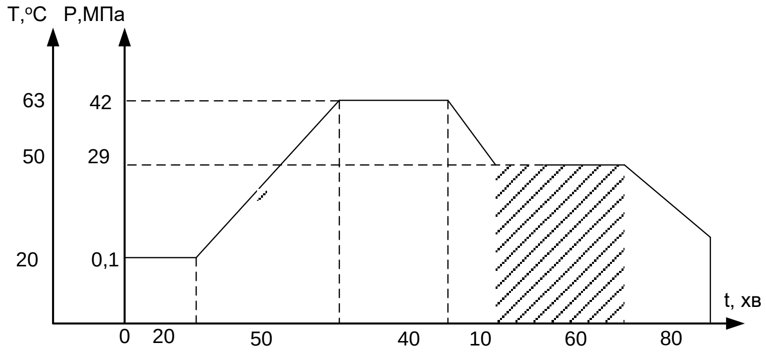

Fig. 3. Diagram of thermobaric and technological conditions of oil-well mortar TC - 100 ПВ testing for cementation of the first section 146×168 mm of operating column at the borehole No. 202 Pivnichna Dolyna

TABLE 4

Oil-well mortar formulation for cementation in the bottom section of the operating column at the borehole No. 202 Pivnichna Dolyna

<table>
<tr><th rowspan="3">Type of the cement</th><th colspan="3">Oil-well mortar composition, Mass portion</th><th rowspan="3">Density of oil-well mortar [g/cm³]</th><th rowspan="3">Spread-ability of oil-well mortar [mm]</th><th colspan="2">Setting terms h.-min.</th><th rowspan="3">Stiffening time h.-min.</th><th rowspan="3">Cement stone strength at bending, in 24 hours [MPa]</th></tr>
<tr><th colspan="2">admixture</th><th rowspan="2">W/C relation-ship</th><th rowspan="2">beginn-ing</th><th rowspan="2">ending</th></tr>
<tr><th>name</th><th>quantity</th></tr>
<tr><td>TC-100 ПВ</td><td>retarder
plasticizer</td><td>0.06
0.2</td><td>50</td><td>1.81</td><td>210</td><td>6-25</td><td>6-55</td><td>4-30</td><td>5.0</td></tr>
<tr><td>TC-100 ПВ</td><td>retarder
plasticizer</td><td>0.04
0.25</td><td>44</td><td>1.88</td><td>200</td><td>3-00</td><td>3-20</td><td>2-45</td><td>5.6</td></tr>
</table>

Conclusion

Implemented investigations evidenced the effectiveness of use of composite oil-well materials in borehole construction at oil-and-gas deposits in cross-border region of Carpathians. Optimal combination of polymineral components of different origin provides in the borehole conditions for the synthesis of the cement stone with the improved operating properties.

References

[1] Nafta i gaz Podkarpacia. Zarys Historii, Instytut Nafty i Gazu, Kraków, Naukowa Dumka, Kijów 2004, 570 p.

[2] Булатов А.И., Проселков Ю.М., Шаманов С.А., Техника и технология бурения нефтяных и газовых скважин, ООО «Недра-Бизнесцентр», М.: 2003, 1008 с.

[3] Саницький М.А., Соболь Х.С., Марків Т.Є., Модифіковані композиційні цементи, «Львівська політехніка», НУ 2010, 130 с.

[4] Terlyha V., Sobol Kh., Tershak B., Modified oil-well cements for casing boreholes with abnormally low stratum pressure, 18th International Conference on Building Materials “18.Ibausil”, 12-15 September 2012, Weimar.

Abstract

In the article there were presented the results of modern composite materials for cementing the boring casing during the construction of boreholes at oil-and-gas deposits of Pry-Carpathians region. Implemented investigations evidenced the effectiveness of use of composite oil-well and oil-and-gas materials and deposit.