Experience in the Application of Water Shut-off and Remedial Cementing Technologies in Fractured Carbonate Reservoirs

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Abstract. The early flooding of reservoirs by the most permeable interlayers in fractured zones is the downside of oil deposits development in carbonate rocks. Conventional methods of water shut-off and remedial cementing used for clastic reservoirs are not universal. This situation determines the need to find and apply new effective methods of enhanced oil recovery, diverter technologies, compositions for water shut-off and remedial cementing in the reservoirs with natural and artificial fracturing. The article shows the results of works performed on water shut-off and remedial cementing in wells, the section of which consists of fractured carbonate reservoirs.

Technologies are noted that showed positive technological efficiency. Application of viscoplastic silicate gels, technologies using high-viscosity oil and hydrocarbon-based cement slurries are the most technologically advanced and relatively low-cost.

Keywords: carbonate reservoir, water shut-off, remedial cementing, water shutoff composition, silicone grouting materials, oil-based cement slurries; silicate viscoplastic gels, polymeric compositions

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Today, experience in the development of carbonate reservoirs is already more than 60 years, which is quite extensive and successful; problem of oil production from carbonate deposits is covered in the scientific literature widely enough.

At the same time, the results of scientific research in the development of carbonate reservoirs are poorly applied in practice. On the one hand, this is due to conventional approaches in the development of carbonates, formed in the period of mass development of highly productive clastic deposits. On the other hand, a variety of geological conditions of carbonate deposits, their properties and characteristics complicate the development of universal optimal technologies for reserves development.

The main feature of the geological structure of carbonate reservoirs is their complex reservoir properties, reflecting the simultaneous presence of voids of various types (cracks, voids, pores). The downside of operating process of oil deposits in fractured carbonate rocks is the early flooding of reservoirs on the most permeable zones (Smekhov, 1974; Tkhostov et al., 1970).

This situation determines the need to find and use in reservoirs with natural and artificial fracturing of new effective methods of enhanced oil recovery, flow diversion technologies, water shut-off compositions and remedial cementing.

In this article we present the results of works on water shut-off and remedial cementing in wells, the section of which is represented with fractured carbonate reservoirs.

The peculiarity of the works on water shut-off and remedial cementing in carbonate reservoirs is that by using aqueous solutions of chemicals, with high penetrating capacity (viscosity of the working solution is close to the viscosity of water) there is no firm adhesion of formed watertight compositions to a hydrophobic porous medium. Cement slurries containing a part of $CaCO_3$, are related to carbonate reservoirs, but because of the large dispersion of the particles have a limited penetration.

Conducting work using hydrocarbon-based cement slurry is perspective in this context (Magadova et al, 2015;. Efimov, 2011; Gaevoy et al, 2012). Their development began in the 1960s in the Russian State University of Oil and Gas named after Gubkin. Currently there are two groups of hydrocarbon-based cement slurry in the market: waterless and emulsion; each is characterized by its own peculiarities. Depending on the fineness of the cement mixture there are three brands of anhydrous hydrocarbon-based cement slurry: “Standard”, “Medium” and “Micro”. Areas of application in the first place, are determined by the type and injectivity of wells. For example, in the carbonate fractured reservoirs with well injectivity 720 m3/day and higher it is better to use the brand “Standard”, and in clastic and carbonate reservoirs with injectivity of 100-150 m^3/day – “Micro”.

The State University of Oil and Gas after Gubkin developed its own selective isolation technology (Efimov, 2011). The main material used in its water-free oil is the most accessible and cheapest selective material in the fields.

Anhydrous cement slurry and hydrocarbon liquid contribute to the formation of high strength and low permeability cement rock with a high degree of adhesion to the rock. Hydrocarbon-based anhydrous cement slurry (HBACS) is cement suspension (48-80 %) with a surfactant composition (0.2-0.5 %) in special hydrocarbon liquid (19.8-41.5 %). After entering water-containing medium the hydrocarbon liquid is substituted with water, HBACS is converted into a thick paste, and then into high-strength and tight cement. Without contact with water the solution is not thickened, separated; it retains their properties over 10 hours. Special hydrocarbon liquid of HBACS can be replaced by oil.

To ensure quality repairs on water inflow isolation in wells with high water cut it is necessary to upload hydrocarbon surfactant solution (emulsion composition) prior to HBACS, which pushes water from borehole, water-repellents the surface of conducting channels and forms a protective shield reverse to water movement into the well through the formation of highly viscous inverse emulsion. Upon contact with oil the emulsion drastically reduces its viscosity and is washed out from oil-conducting channel. Emulsion composition consists of 80% oil, 15% fresh water and 5% surfactant-repelling agent "Neftehimeko".

Tests on HBACS were carried out in 2008-2009 in the wells of JSC "Orenburgneft", containing in the section carbonate reservoir section with injectivity on the water of 550-700 m^3/day (Table 1) (Efimov, 2011; On the application of new materials ... 2013). In almost all the wells marked increase in oil production and reduced water cut. Dynamics of production rate and water cut in the well 57 of Dolgovsky field in 2008-2010 showed that the use of HBACS provides long-term effect.

Selective isolation technology was tested in 2010 in LLC "RN-Purneftegas" and JSC "Gazpromneft-NNG" in wells of Barsukovsky and Sugmutsky fields with water content of 93.6 to 99%. The liquid flow rate of individual wells before remedial cementing was 350-800 m^3/day, while oil production does not exceed 8 tons/day. As a result of the selective isolation water content is reduced and oil production is increased.

The paper (Kadyrov et al., 2010) describes the experience of the application of high-viscosity oil for water shutoff in carbonate reservoirs.

One of the strategic directions of PJSC Tatneft is to engage in the development of the reserves of heavy and bituminous oil. This oil on its physical-chemical parameters is prospectively to use in the water inflow control technology in carbonate reservoirs (Kadyrov et al, 2008;. Kandaurova et al, 2008). The developed technology is based on the injection into the insulated layers of oil-well portland cement suspension in a preheated mixture of high-viscosity oil in North and South domes of Mordovo-Karmalsky field. Oil at 20°C has a density of 935-949 kg/m3, dynamic viscosity of 360-4200 mPa*s (at 20 °C) to 14-60 mPa*s (at 80 C). Used mixture of oil has a density of 940-942 kg/m^3 at 20 °C and dynamic viscosity of 480-500 mPa*s (at 20 °C) to 17-18 mPa*s (at 80 °C).

When suspension enters the watered formation, plugging of water flow channels occurs due to cement hardening. In oil saturated intervals suspension is diluted with oil and washed out of the reservoir, indicating on the technology selectivity. Insulation screen in the initial period of formation can withstand the current pressure drop due to multiple increase of the viscosity of heavy oil when it cools to the temperature of the reservoir.

In order to prevent cooling of the suspension during the injection into formation, special insulated pipes are used with screen-vacuum insulation type (thermocase). Each tube consists of inner and outer tubes, in the annulus vacuum is made of 1 x 10 4 mm Hg, acting as a thermal insulation layer. Thermally insulated pipes are interconnected with coupling with an insulating sleeve. When pumping the heated water at a rate of 4 l/s through the insulated tubing string with length of 1000 m the temperature is reduced by 2 °C.

This technology was tested in the fields of oil and gas production department Leninogorskneft in 20 wells of 301-303 deposits of Romashkino field confined to Vereiskian, Bashkir and Serpukhov carbon deposits with a complex geological structure. Carrying water shutoff in the geological and technical conditions of these deposits is a challenge, and the majority of the previously used technologies are inefficient. The results of the proposed technology are presented in Table 2 (Kadyrov et al., 2010). Average oil production per well increase of 1.6 t/d, additional 5091 tons of oil is produced. The average duration of the current effective period is 158 days.

Both options of technologies can be used during water shutoff in both carbonate and clastic reservoirs, including alignment of wells injectivity profile.

The work (Kadyrov et al., 2014) provides a method to reduce water flow using water-swellable polymers.

Application of the most water-swellable polymer options is inefficient, as they swell in water indefinitely. Unlimited swelling effect leads to a reduction of the method duration. Currently used grades of water swellable polymers almost don't swell in highly mineralized formation water. Thus, the extent of absorption from the swellable polymers currently used in PJSC Tatneft of series AK-639, brands V415 and V615 in the mineralized formation fluids is significantly reduced, which limits their field of application and complicates the process. Elastomers (polymers having elastomeric properties

Well No.	Filed	Liquid flow rate, m^3/day		Water content, %		Oil production, m^3/day		Flowing level, m	
		before remedial cementing	after remedial cementing	before remedial cementing	after remedial cementing	before remedial cementing	after remedial cementing	before remedial cementing	after remedial cementing
57	Dolgovsky	80	60	92,5	65	6	21	1200	1000
340	Sorochinsko-Nikosky	168	175	75	65	42	68	2000	1522
566	Sorochinsko-Nikosky	62	103	57	57	26	58	1950	1528
527	Berezovsky	100	20	95	24	4	13	143	238
1031	Bobrovsky	26	75	75	85	5,3	9,3	989	1166

Table 1. The test results of hydrocarbon-based anhydrous cement slurries on JSC "Orenburgneft" in 2008-2009.

in operating range) based on the water-swellable rubber and urethane crumbs also swell poorly in formation water; furthermore, such products have a very high cost.

In this regard, Saratov factory of acrylic polymer "AKRIPOL" designed swellable acrylic copolymer, the molar fraction content of sodium acrylate a = 0.3 and the degree of crosslinking in the range m = 0.01-0.05 % (mole) (Bayburdov et al. , 2009). In experiments to determine the insulation coefficient samples were used of dried and crushed gel copolymer prepared in the laboratory by copolymerization of acrylamide and sodium acrylate in concentrated aqueous solutions (with a mass concentration of 20%) in the presence of a hydrophobic acrylic copolymer, crosslinker (N, N'-methylene-bis-acrylamide) and redox initiator system (ammonium persulfate and sodium metabisulfite).

The degree of swelling in fresh water is up to 2000%, and in the formation of up to 1200% for 24 hours, which is quite acceptable for the preparation of water shutoff compositions. This water-swellable polymer reagent with the increased elasticity of water-swollen polymer particles is put on production according to TU No. 2216-016-55373366-2007 marked with V 50E (Table 3).

The technology with developed water shutoff system is implemented in the process of implementation of ODA in four wells of "Tatneft" (Kadyrov et al., 2014).

It was found that the use of water shutoff technology systems based on acrylic copolymer powder suspension of brand 50E in an aqueous solution of surfactant DP9-8177, allowing to keep plugging ability over a long period of time, is the most promising in fractured porous and cavernous fractured carbonate reservoirs at work on insulation of bottom water tributaries or complete isolation of washed layer.

At the same time, water-swellable polymer of series AK-639, which is a "hardwired" surfactant (FSUE Saratov Scientific Research Institute of Polymers), was previously tested in the fields of the Samara region and the Republic of Tatarstan and has shown good efficiency (Berlin, 2011; Kurochkin et al, 2006). Powder compositions of "hardwired" polymer AK-639 with concentration of 0.5-1 % were injected in small portions and pushed from well by water with density of 1.18 g/cm^3. This polymer is capable of absorbing water (1 g of water-swellable polymers – up to 100-400 g of water) and is used to align the injectivity profile of injection wells. Gelation occurred at approximately 70 °C only when in contact with water for 24-28 hours. Additional oil production in the surrounding additional wells was 3575 tons or about 7 thousand tons/ton of injected polymer solution. The duration of the effect is 1.5 years. The work (Ibragimov et al., 2015) presents the results of swellable packers to isolate sections of fractured horizontal wellbores.

High speed of wells watering characteristic for deposits 302-303 of Romashkino field, is linked to their geological

Well No.	Date of treatment	Oil production, t/day	Liquid flow rate, t/day	Water content, %	Oil production, t/day	Liquid flow rate, t/day	Water content, %	Additional oil production, t	Average oil production, t/day	Operation time, days
		Before treatment			After treatment					
37908	20.04.07	1,0	8,2	89,1	3,9	6,7	42,6	791	2,0	399
26462	19.07.07	0,1	6,1	98,6	2,4	4,8	50,7	153	0,6	242
26531	11.07.07	0,1	5,1	94,6	4,3	9,2	53,7	1072	3,2	335
15483	24.08.07	0,1	5,0	98,3	1,1	6,8	83,7	80	0,3	260
37539	14.09.07	0,2	4,0	90,2	2,5	4,3	40,7	597	2,2	275
38187	20.09.07	1,5	7,9	94,6	5,1	14,2	64,4	269	2,2	124
38222	02.11.07	0,2	14,2	99,1	4,8	14,2	66,3	128	0,8	169
38168	22.02.08	0,2	8,0	97,3	2,7	11,9	77,0	114	0,9	124
37985	09.02.08	0,4	7,5	95,5	3,0	9,6	69,2	168	1,2	137
26476	15.02.08	0,0	3,3	99,1	4,2	11,7	64,4	173	1,4	121
18067	30.01.08	0,0	8,1	98,2	3,6	9,8	63,5	384	2,7	140
37947	22.02.08	0,2	5,4	95,5	1,4	6,5	77,9	170	1,4	118
38305	08.03.08	0,6	8,9	95,5	3,3	11,8	72,1	139	1,3	110
37956	01.03.08	0,3	12,1	97,3	2,0	15,0	86,4	87	0,7	118
35807	17.03.08	0,5	6,4	95,5	3,2	10,9	70,3	266	2,7	99
42	07.04.08	0,2	3,0	99,1	2,3	2,9	20,9	46	0,7	67
38317	19.03.08	0,4	8,6	97,3	2,5	9,9	75,0	113	1,2	97
17523	12.03.08	0,5	11,8	94,6	3,6	17,9	79,7	169	1,6	106
38071	24.03.08	0,0	4,6	95,7	1,2	6,5	81,6	33	0,3	95
26694	10.06.08	2,5	13,8	82,1	5,8	9,9	41,0	139	4,3	32

Table. 2. The results of the use of water inflow control technology in carbonate reservoirs with high-viscosity oil.

Model No.	Weight content of elements, %, in technological solution		Isolation coefficient, %, through		
	surfactant DP9-8177	acrylic copolymer B 50Э	24 hours	6 mon.	12 mon.
1	0,1	0,5	95	93	90
2	0,3	0,8	96	94	91
3	0,5	1	98	96	95
4	0,5	1,5	100	98	96
5	0,5	2,0	100	99	98

Table 3. The results of the solution testing for water shutoff, containing swollen particles of water-swellable polymers.

features: high layered and zonal heterogeneity; low reservoir properties of rock matrix; the presence of cracks, by which mainly produced water is moving; increased oil viscosity; low gas-oil ratio. Construction and operation of horizontal wells and sidetracks with horizontal termination in such circumstances involves the risk of progressive irrigation of wells.

To isolate the fractured areas in the construction of wells in the framework field trials, the technology of horizontal shaft casing with swellable packer. TatNIPIneft together with SC "Kvart" (Kazan) developed rubber polymeric water-swellable elastomer to create a swellable packer (Kateyev et al., 2014). Water swellable packer with length of 1 m, outer diameter of 133 mm to 114 mm in the casing, a tube with inner diameter of 145 mm after swelling in water of different salinity withstands breakdown pressure of 10 to 25 MPa. It is resistant to acid composition, which is used in PJSC "Tatneft" for enhanced oil recovery.

Field tests of water swellable packers are conducted during drilling 35387g (Fig. 1a), 37852g and repair of wells 37972g (Fig. 1 b), 37783g, deposits 302-303 of oil and gas production department Leninogorskneft. After the packers drain as part of the liner casing their swelling and leak tightness is checked by fluid injection on a packer installed in the 'head' of the liner casing. Table 5 presents the operating results on (25.05.2015) for wells 35387g, 37852g and neighboring wells with different options of completion: a cemented liner with perforations; non-cemented liner.

The experience is interesting in the development of TatNIPIneft (Medvedeva, 2014) of APS technology, which is based on the use of reinforced polymer systems based on water-soluble polyacrylamide DR9-8177. Development was carried out in the direction of modifying the structure-forming compositions by the addition of reinforcing additives used to reinforce cement products (Babenkov, 2007). The following products were used as fillers: water-insoluble oxides of divalent metals (ZnO, MgO), inorganic silicate fibers (glass fiber production of Tatneft-Elabuga) and various fiberglasses (VSM of company "C Ireland", basalt fiber of LLC "Russian basalt").

The formulation of composition and technology on its basis were developed primarily for high-permeability clastic reservoirs and carbonate reservoirs of fractured and fractured-pore type for use in technologies to increase oil recovery and reduce water in production wells. The compounding composition is developed with optimal processing properties: the concentration of surfactants of 0.7% to 1.0%, metal oxide from 0.05% to 0.08%, chromium acetate from 0.06% to 1.0%, reinforcing fibers 0.05% to 0.3%.

The oil and gas production department "Leninogorskneft" conducted pilot projects in three producing wells 35298, 35599, 37828 of deposit 303, Romashkino field, penetrated carbonate reservoirs in Protvinskian horizon. After the work on the implementation of the APS technology there was a significant decrease in water cut and growth of oil production rate. The growth of oil production rate per wells 37828,35599,35298 was 5.8 m^3/day 2.7 m^3/day, 7.5 m^3/day, respectively; water content decreased by 86%, 40% and 70%, respectively. It is possible to draw preliminary conclusions about the success of field tests conducted.

One of the method on reducing the limit inflow of water of different nature in the production wells is the technology of pumping viscoplastic silicate gels, gel-forming silicate compositions based on liquid glass (alkali silicate gel) and crystalline sodium metasilicate (acidic silicate gels).

Silicate gel is formed with time at elevated temperature from low viscosity solutions and is a structured system,

Well No.	Operating time, days	Interval of liner installation, m	Flow rate		Water content, %
			of liquid, m^3/day	of oil, t/day	
Bashkir stage					
35387г	303	950-1126 (with packer "Kvart")	4,4	2,95	26,0
35384г	280	838-1022	13,0	0,17	98,5
35393г	170	847-1047	2,5	1,99	12,0
37723г	259	940-1165	11,3	5,43	47,0
37729г	174	950-1123	1,6	1,27	12,0
37855г	240	942-1110 (with packer TAM)	12,8	5,57	52,0
37551г	314	892-1169	12,9	1,63	86,0
37853г	291	948-1094	12,7	1,61	86,0
Protvinsky horizon					
35391г	281	766-1017	10,0	1,09	88,0
37852г	332	887-1048 (with packer "Kvart")	12,5	4,92	57,0
37854г	251	933-1136	13,2	2,29	81,0

Table 4. Operation results of wells 35387g, 37852g and neighboring wells with different variants of completion.

sometimes additionally hardened with polymer (surfactant, hydrolyzed polyacrylonitrile). The resulting gel can withstand large pressure gradients. Silica gels are stable over time at elevated temperature and salinity.

The Saint-Petersburg State Mining University (Nikitin, Petukhov, 2011) developed an insulating compound called SPMI-1. Liquid glass with module 2.9 of the commodity form containing sodium silicate 46.77%, chromium acetate 55% of the commodity form and 55% fresh water were used as components. Total 80 formulations were prepared, which differed in concentrations of sodium silicate, chromium acetate and composition extract temperatures.

It was found that the formulations with most optimum characteristics of gel processing and strength have a concentration of 3.3% sodium silicate and 1.1-1.38 % chromium acetate on exposure to formation conditions for 24 hours. More accurate reactant concentrations are selected based on filtration experiments on core deposits samples.

The advantage of all silica gels is in the possibility of destruction in the well and reservoir conditions by alkali solutions. The most effective use of such compounds is for insulation of casing circulation and isolation of bottom water.

The works (Solovyev et al, 2011;. Provedenie remontno-izolyatsionnykh rabot..., 2013) considered remedial cementing in wells using RELCOM polymer composition on the fields of Udmurtia and the Urals-Volga region.

The scientific and production center “Complex-Oil”, Ufa, has developed a new polymer reactant based on acrylic acid RELCOM, which is produced by the original technology. In the chemical composition compared to peers it has a wide range of functional groups in the macromolecule with minimal branching, therefore it has higher coagulating and adsorption activity that contributes to the formation of durable water shutoff screen (Solovyev et al., 2011).

Physical and chemical nature of the residue-forming technology with a polymeric reagent RELCOM is that in the reaction in situ of RELCOM with reagent-crosslinker heat resistant rubber-like precipitate is formed in the form of a sticky polymer mass having good adhesion to the reservoir and the cement stone, which is resistant to erosion by fresh and saline water. Solutions of polyvalent metal salt or brine water are used as reagents-crosslinkers.

Table 5 shows the results of the increase in oil production and reduction in water cut after the treatment of bottom-hole zone of producing wells at the fields Belkamneft by technology using polymer RELCOM.

The paper (Alonov, Bobrikov, 2009) presents previously published articles and reports that show the experience of the application of silicone grouting materials ACOR and compositions on their basis on Russian fields, the Republic of Belarus and the Republic of Kazakhstan. The generalized results and the criteria for the selective isolation of water inflows are considered, the efficiency of remedial cementing is analyzed to limit the water inflow in oil and gas fields, the ways and prospects are given for the development of organosilicone grouting materials.

The experience in the application of the material ACOR-BN 102 is shown on Zlodarevsky field of Perm Krai. The productive horizons occur at depths of 1050-1550 meters and are composed of carbonate (limestone and dolomite) and clastic (argillites, siltstones and sandstones) rocks. Effective thickness of layers is 2-3.5 m. The porosity (for well 310 of Kashirskian and Bobrikovian deposits) is 10-20 %, permeability is 0.33 mm^2, reservoir temperature of 23.5-27 °C, current reservoir pressure of 8.5 MPa, paraffin content of 3.3-3.5 %. Results of the technology test are shown in Tables 6,7.

The article (Lymar, 2011) reviewed the results of field tests in wells of oil fields of the Republic of Belarus, water shutoff compositions based on chemical reactants GPAN, OVP-1 and ACOR-BN 102, as well as a new method for the selective isolation and integrated technology.

Oil deposits of the Republic of Belarus for the most part are confined to the deposits of the Devonian system and presented on 85-90 % of the carbonate rocks (pre-salt and intersalt complexes). The depth of their occurrence vary from 2.000 to 4.000 m. Average values of effective thickness are in the range of 10-120 m, reservoir temperatures – 50-90 °C. Mineralization of associated and formation waters varies from 140 to 340 g/l.

Studies performed in BelNIPIneft revealed that the VIS on the basis of chemical reactants A-KOR-BN102, GPAN and OVP-1 to a greater extent of the tested chemicals meet the necessary requirements (Lymar, 2011; Lymar et al., 2007b; 2006; 2003).

Well No.	Well operating indicators before treatment			Well operating indicators after treatment			Average daily oil production, t/day / oil flow rate increase, %	Decline of average daily water production, m^3/day / Decline of average daily oil production, %	Duration of effect, months
	Average daily production of			Average daily production of					
	liquid, m^3/day / water content, %	oil, t/day	water, m^3/day	liquid, m^3/day / water content, %	oil, t/day	water, m^3/day			
6725	327,0/99,8	0,6	326,3	15,0/82,0	2,4	12,3	1,8/300	314/96,2	17
130	22,0/80,0	3,9	17,6	5,6/13,2	4,4	0,7	0,5/12,8	16,9/96,0	12
132	15,0/93,3	0,9	13,9	16,7/85,2	2,95	7,1	2,05/227,8	6,8/48,9	8
255	17,3/82,0	2,6	14,2	13,4/52,0	5,4	7,0	2,8/107,7	7,2/50,7	15
229	23,0/87,8	2,5	20,2	11,5/74,0	5,0	8,51	2,5/100,0	11,6/57,4	16
223	16,0/81,0	2,6	13	17,1/70,7	4,2	8,0	1,6/61,5	5,0/38,5	15

Table 5. Main application results of RELCOM polymer on fields of “Belkamneft”.

Deposits	Oil saturated thickness, m	Type of water cut	Injection volume, m^3	Oil flow rate, t/day		Water cut of production wells, %		Duration of effect
				before remedial cementing	after remedial cementing	before remedial cementing	after remedial cementing	
C_{1v}	3,3	Bottom	6,0	1,0	2,6	80,1	39,0	More than 5 mon.

Table 6. The results of remedial cementing in production well 310 of Zlodarevsky field.

Deposits	Injectivity, m^3/day		Injection pressure, MPa		Duration of effect
	before remedial cementing	after remedial cementing	before remedial cementing	after remedial cementing	
C_{1v}	275	130	5,0	10,0	continued

Table 7. The results of remedial cementing in injection well 304 of Zlodarevsky field.

GPAN and OVP-1 are new domestic chemical reactants for water shutoff (Lymar et al., 2007b, 2006; Brilliant, Kozlov, 2000; Lymar et al., 2008). GPAN is hydrolyzed polyacrylonitrile with modified fructose sulfonol additives. OVP-1 is alkaline hydrolyzate of technological waste of polyacrylonitrile fibers modified with special additives. The raw materials are used for its production of waste of technical fiber "Nitron" and chemical fibers (KNOPS), the suppliers of which are Belarusian enterprises JSC "Polymir" and JSC "Belfa". ACOR-BN102 developed by SPC "Nitpo" organosilicone composition with various modifying additives (Lymar et al., 2007a).

Conducted field tests of new water-isolating compositions confirmed the high efficiency of the proposed technologies. Six well operations are performed (Lymar et al., 2007a). Consumption of water-isolating compositions ranged from 5 to 30 m3 per well operation. All works are successful technologically and economically profitable (Table 8).

In the development of new technological schemes and techniques of water limiting operations, tests are performed for the technology of selective isolation of water flow using water-isolating compositions based on chemical reactants ACOR-BN 102, GPAN and OVP-1 and injection of water-isolating compositions in the pulsating mode.

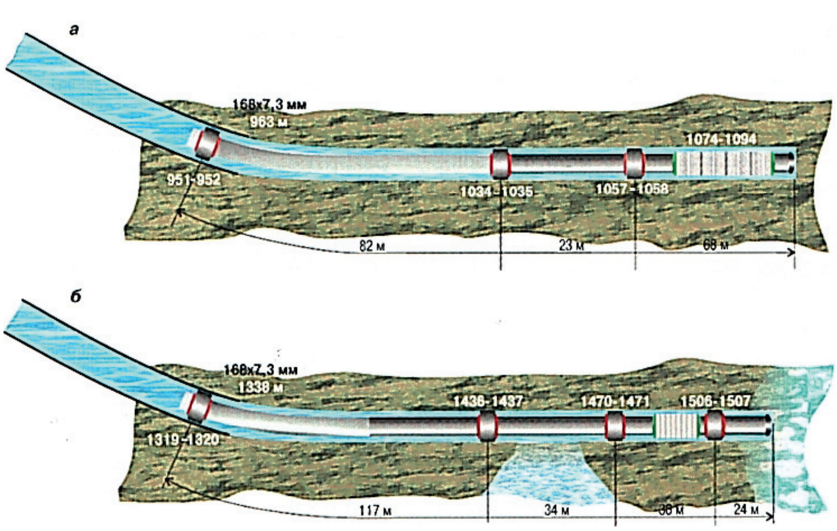

Fig. 1. Layout of the liner in wells 35387g (a) and 37972g (b).

These technologies are easy to implement, have low labor intensity, lack of complex technological operations, requiring the use of high-level experts, short duration and cost. They included:

- Water-isolating compositions to reduce injectivity of the reservoir: 10 m^3 of CMC solution and 6 m^3 of viscous liquid buffer on the basis of surfactants;

- Residue-forming compositions: 90 m^3 of 50% solution "Lignopol" and 4.9 m^3 of solution "GPAN";

- Gelling compositions: 17 m^3 of solution PAA DR-9 (175 kg of commodity-based) with 1.7 m^3 of $Al_2(S0_4)_3$ (0.35 t of commodity-based) and 11.8 m^3 solution of reagent "ACOR-BN102".

Completed pilot tests of water inflow solation technology in a horizontal wellbore confirmed not only the effectiveness of the proposed selective waterproofing technology in terms of oil deposits of the Republic of Belarus, but also the efficiency of the developed water-isolating compositions based on chemicals GPAN and ACOR-BN 102 (Lymar et al., 2006) .

Another promising direction in the implementation of new

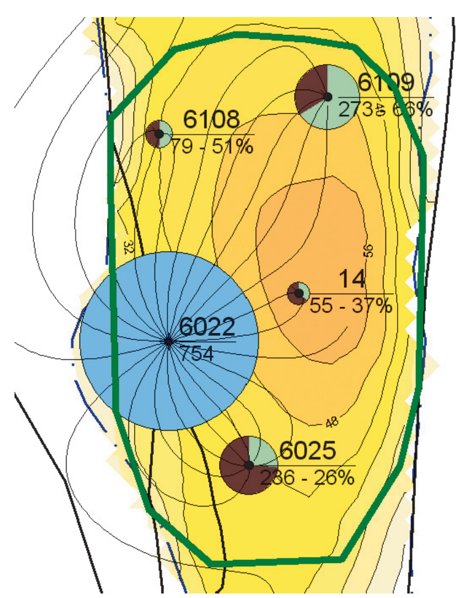

Fig. 2. Map tile of current development conditions state in the area of well 6022 of Nyadeyyusky field as of 01.06.2008

Main chemical reactant of water-isolating composition	Well No.	Field	Type of activities*	Additional oil production, t	Average oil production, t/day
A-KOR-BN102	36	Dubrovsky	OOI	4891	3,4
	37	Dubrovsky	OOI	13027	4,5
GPAN	55	Malodushinsky	OOI	4556	2,8
	115	Yuzhno-Ostashkovichsky	LZP	4866	3,9
OVP-1	144	Yuzhno-Sosnovsky	LZP	17121	14,3
	57	Ostashkovichsky	OOI	38944	24,2

*Table 8. The results of field tests when testing new water-isolating compositions in the wells of oil fields of the Republic of Belarus. * OOI – clipping of watered intervals, LZP – Abandonment of slaughtered flows.*

technological methods of isolation of water-inflow is tested in terms of wells the oil fields of the Republic of Belarus injection technology IPOs in the low-frequency pulsed exposure mode (Lymar et al., 2003).

The need for research in this area is due to the widespread introduction of water-isolating compositions with the contact mechanism of TM formation based on chemical reactants: hydrolyzed polyacrylonitrile, liquid glass, GPAN, OVP-1 and others.

Technology to reduce water inflow with similar water-isolating compositions includes sequential batch injection into the reservoir of residue-forming solutions and the precipitator (staple), separated by a buffer liquid. A special case is the reaction of water-isolating composition with the formation water. It is assumed that in the formation their mixing occurs to form a TM.

The effectiveness of water inflow insulation depends on the nature of the reagents and reaction mixing ratio (mass transfer) of solutions of residue-former and precipitator, which determines the amount and rate of the resulting reaction product, overlapping filtering channels.

One of the promising ways of increasing the effectiveness of work with the residue-forming compositions should be considered as the development of integrated technologies, including various methods of influence.

To enable mass transfer in porous media, uniform injection on the formation, increase in volume of formed TM, its strength and adhesion to rock, the injection technology of water-insulating composition into the formation in low-frequency pulsed exposure mode (Lymar et al., 2003).

New technology tests were carried out in the well 45 of Dubrovsky field. The effectiveness of the proposed technology is confirmed by comparing indicators of water-limiting operations made in similar geological and technical conditions of wells 45 (integrated technology) and 43 (standard technology) of Dubrovsky field. New technology compared to the standard one did not only increase the efficiency of water-limiting operations, but also reduces the consumption of water-insulating compositions by 2-3 times (Lymar et al., 2008).

Currently, on the oil fields of the Republic of Belarus pilot tests are conducted for the water-isolating compositions of the next generation on the basis of chemical reactants OVP-2 and various kinds of surfactants and coil tubing technologies. The paper (Ismagilov et al., 2013) shows the results of the application of waterproofing in cracks of carbonate reservoirs in deposits Val Gamburtseva. Key features of Nyadeyyusky, Cherpayusky, Khasyreysky deposits are presented in Table 9.

The main problems in the development of these deposits is a water breakthrough in production wells 2-3 months after the

Deposit	Nadeyyusky	Cherpayusky	Khasyreysky
Reservoir type	Porous fractured cavernous	Fractured cavernous porous	
Average bedding depth (absolute depth mark), m	-2138	-2404	-2183
Oil saturated thickness, m	23	35,6	30,4
Core permeability, 10^{-3}micron^2	8,9	8,9	9,6
Average porosity, un.fr.	0,08	0,07	0,08
Initial reservoir pressure, MPa	23	25	23,8
Initial reservoir temperature, ºC	42	42	40
Oil viscosity, mPa×s	2,34	2,34	2,8
Gas content, m^3/t	127	117	102

Table 9. Geological and physical indicators of deposits Val Gamburtseva.

Field	Number of well operations	Years of treatment	Additional oil production, thous.t		
			Decrease of water cut	Stimulation of liquid withdrawal	total
Nadeyyusky	20	2008-2012	141,3	-35,2	106,1
Khasyreysky	11	2009-2012	93,0	-30,6	62,4
Cherpayusky	4	2010-2011	5,2	0,4	5,4
Total	35		239,5	-65,4	174,1

Table 10. The main application results of the technology on deposits Val Gamburtseva in 2008-2012.

start of injection into injection wells along fractures, mainly in submeridian direction.

As an example, the results are giving of water inflow limitations in production wells by pumping composition of “strong gel” developed by LLC “RN-UfaNIPIneft” on the basis of polyacrylamide and stapler.

As the staple aluminum citrate [$C_3N_4ON\ (COO)_3$]A1 was used. Composition injection was carried out in the injection well 6022 of Nyadeyyusky field (Fig. 2).

During the execution of works 3 packs of the composition were injected at a concentration of surfactants 0.57% (insulation), 0.46% (squeezing) and 0.6% (strengthening), total – 1 000 m^3.

After the works completion there was a significant decrease in water cut of surrounding production wells (10-15 %) and the stabilization of oil production. Additional oil production amounted to more than 30 thousand tons.

In general, from the application of this technology in the fields of Val Gamburtseva in 2008-2012 additionally 174.1 thousand tons was produced with an average technological efficiency of 4.97 tons of additional oil per 1 well operation (Table 10).

Conclusions

1. The complex reservoir properties of carbonate reservoir lead to early water cut on the most permeable interlayers in fractured zones in the exploitation of oil deposits.

2. The main objectives of improving the remedial cementing technology in carbonate reservoirs are reducing the cost and improving the efficiency of work, which can be solved in two main areas: the introduction of new water shutoff compositions and development of various technological schemes and techniques.

3. Conventional methods of water shutoff and remedial cementing used for clastic reservoirs are not universal, which determines the need to find and use in reservoirs with natural and artificial fracturing of new effective methods of water shutoff and remedial cementing.

4. Positive technological efficiency in fractured carbonate reservoirs showed the following technologies of water shutoff and remedial cementing:

- Cement slurries based n hydrocarbons;
- Heavy oil or bitumen for water shutoff;
- Water-swellable polymers;
- Swellable packers to isolate fractured sections of horizontal wellbores;
- Injection of viscoplastic silicate gels and polymer compositions;
- Silicone grouting materials ACOR and preparations based thereon.

5. The use of viscoplastic silicate gels, technologies using hydrocarbon-based cement slurries and high-viscosity oil are relatively low-cost and the most technologically advanced in comparable technological efficiency.

6. The development of relevant innovative complex technologies are perspective including both water shutoff and remedial cementing, as well as various methods of influence with the use of physical fields.

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