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REVIEW OF NEW WATER SHUT-OFF TECHNOLOGIES IMPLEMENTED ON THE OIL FIELDS OF THE REPUBLIC OF BELARUS

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Abstract. *A brief review of new water shut-off technologies developed by BelNIPIneft and tested on the oil field wells in the Republic of Belarus. The results of pilot testing of water shut-off compositions based on chemical agents "GPAN", "OVP-1" and "AKOR-BN102" are being discussed as well as new method of selective water shut-off and integrally designed technology. It is demonstrated that application of developed technologies allows significant increase of technical-economical performance of water shut-off works.*

Keywords: *water shut-off works, water shut-off compositions, plugging material, selective shut-off, integrally designed technology, technical-economical performance*

Deposits of Belarusian oil fields are basically confined to sediments of Devon system and represented by 85 - 90 % of carbonate rocks (subsalt and intersalt assemblages). Occurrence depths differ from 2000 to 4000 m. Average values for net sand pays range within 10 - 120 m, for formation temperatures – 50 - 90 °C. Salinity of associated and formation waters changes from 140 to 340 g/l.

The largest oil fields are at their final development stage, defined by growth of negative factors, conditioned by both objective and subjective reasons: uneven recovery of reserves, increase of watercut, increase of the part of hard-to-recover reserves, ageing and depreciation of production and injection well stock, etc.

In order to compensate permanent losses, decrease production decline rate and activate recovery of reserves the large set of workover operations is carried out, the most important role in which is given to water shut-off works.

Annually on the largest oil fields of Belarus 20-30 wells are prematurely water cut, which requires water shut-off works in order to cut the watered intervals, eliminate behind-the casing flow and perform selective shut-off.

The complex type of geological conditions of oil deposit occurrence, filtration heterogeneity of reservoirs, wide range of physical-chemical properties of oil and produced waters quite often don't make possible to implement many of well-known water shut-off technologies. In this connection BelNIPIneft carries out task-oriented program of scientific and engineering works, searching, testing, adaptation and implementation of the most advanced foreign technologies as well as the own-developed ones.

The main tasks of improvement of water shut-off technologies are: cost reduction and increase of work efficiency. The studies are held in two main directions: imple-

mentation of new water shut-off compositions and development of different process flow schemes and methods [5].

In the first direction there was carried out wide range of works in development, adaptation and implementation of water shut-off compositions corresponding to special geological-technical and physical-chemical conditions of Belarusian oil fields. In the frame of large-scale operations the main requirements for water shut-off compositions were determined (Table 1), some ten chemical agents and based on them water shut-off compositions were tested [5, 7].

Table 1. The main features of water shut-off compositions and plugging materials (PM) formed by them, corresponding to the conditions of Belarusian oil fields

Title of parameters for water shut-off compositions and plugging materials	**Description and value of parameters**
Viscosity	Ability to control viscosity within the limits of 10 - 150 mPa·s
Structural peculiarities; deformation and strength properties	Tight, homogenous and flexible texture of all plugging materials High deformation and strength properties of plugging materials, decreasing permeability of large fractures with diameter 1 - 3 mm about 3 times. No fracturing of plugging materials while drilling out cement bridge, no loading and vibrating while operating pumping units, no pressure fluctuations. Formed plugging material is acid-resistant.
Stability in reservoir conditions	Stability of plugging material (no shrinkage and oil separa-ting/syner-esis) in reservoir conditions under contact with high-mi-neralized wa-ters during quite a long period (more than 300 days).
Adhesion	In case of formation of homogenous structure – high adhesion of plug-ging materials to the rocks, cement stone and metal. No adhesion while plugging material is being composed in the form of residuum.
Production effectiveness	Possibility of density control within the limits of 1 - 1,2 g/sm^3. Good diffusion for quick mixing with hardening agent (non-solvent, crosslinker). Possibility of adding modifiers and fillers. Small number of components, transportability, convenience while repeated packing, storing etc. Production effectiveness while mixing and applying. In-duction period of structure forming is controlled and sufficient for in-jection of the whole planned volume of water shut-off compositions into reservoir. Low adhesion of water shut-off compositions to the sur-face of details of oil production equipment. Storage, transportation, mixing and application in conditions of low temperatures (winter peri-od).
Safety	Safety while transporting, mixing, applying: low toxic level (class of hazard – not lower than 3), low flammability level, etc. Ecologically safe.
Technical-economical performance	Availability of providers and reasonable cost

By adopted practice BelNIPIneft studies water shut-off compositions in three stages: laboratory, model and field tests.

Laboratory tests are performed by one of two techniques depending on mechanism of plugging material formation.

After mixing, gel-forming water shut-off compositions are placed into heating cabinet and are cured under high temperatures (60 - 80 °C). Then the following parameters are being evaluated: time of gel formation, structural-mechanical and adhesion characteristics of plugging materials, behaviour of mechanical and adhesion parameters while contacting with formation (mineralized) water and acids, stability (no shrinkage and oil separating/syneresis) in reservoir simulating conditions.

After being prepared, sludge-forming water shut-off compositions are mixed with non-solvent (sludge initiator), placed to the heating cabinet and cured under formation temperature (60 - 80 °C). During this the following parameters are determined: the volume of formed sludge before and after centrifuging, structural characteristics of the formed sludge, their behavior while contacting with formation (mineralized) water and acids, stability (change of volume and properties of sludge in time) in reservoir simulating conditions.

Sludge-forming water shut-off compositions are also tested by the method of «lamination» of the equal volumes of non-solvent (sludge initiator) on the studied shut-off compositions. After curing under formation pressure (60 - 80 °C) structural-mechanical characteristics of plugging material formed on the boundary line are determined.

Model tests are carried out on the core permeability measurement unit using bulk (de-agglomerated rocks) of water-saturated formation models.

Procedure. By method of direct pumping produced water is pumped through the model (ρ = 1,13 - 1,17 g/cm^3) in order to determine the permeability index. Then the fringe(s) of studied water shut-off compositions are pumped (compositions with contact mechanism of plugging material formation and solutions of non-solvent or gel-forming initiator are separated by flushing fluid). The model is cured under formation temperature during the time specified in the program of the studies, after that produced water is pumped through the model by method of reverse pumping.

Pore volume of formation model is determined by the volume of produced water, incorporated in the model while vacuuming.

The criteria for evaluation of efficiency of water shut-off compositions are the following: change of permeability and pressure of reservoir model while injecting water and water shut-off compositions.

Performed studies let us prove, that water shut-off compositions based on chemical agents “AKOR-BN102”, “GPAN” и “OVP-1” meet the requirements far better than the other tested compositions [4, 5, 6].

“GPAN” and “OVP-1” are new domestic chemical agents for water shut-off [2, 3, 4, 5]. “GPAN” is hydrolized polyacrylonitrile with modifying fructose and sulphonol

additives. “OVP-1” – alkaline hydrolizate of technological wastes of polyacrylonitrile (PAN) fiber, modified by special additives. As a raw material for its mixing wastes of technical fiber “Nitron” and chemical fibers (KNOPS), provided by Belarusian enterprises JSV “Polymir” and JSV “Belfa” are used

“AKOR-BN102” – developed by NPF “Nitpo” organic-silicon composition with different modifying additives [7].

The results of model tests of new water shut-off compositions are given on the Fig. 1 - 3.

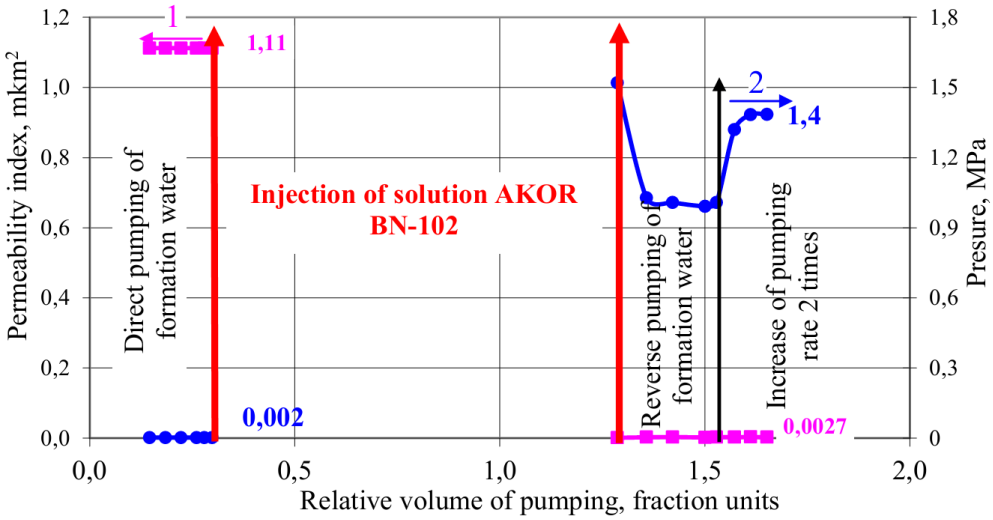

Fig. 1. Behavior of pumping pressure and permeability of water-saturated reservoir model after its treatment with water shut-off compositions based on “AKOR-BN102”:
1 – permeability factor; 2 – pumping pressure

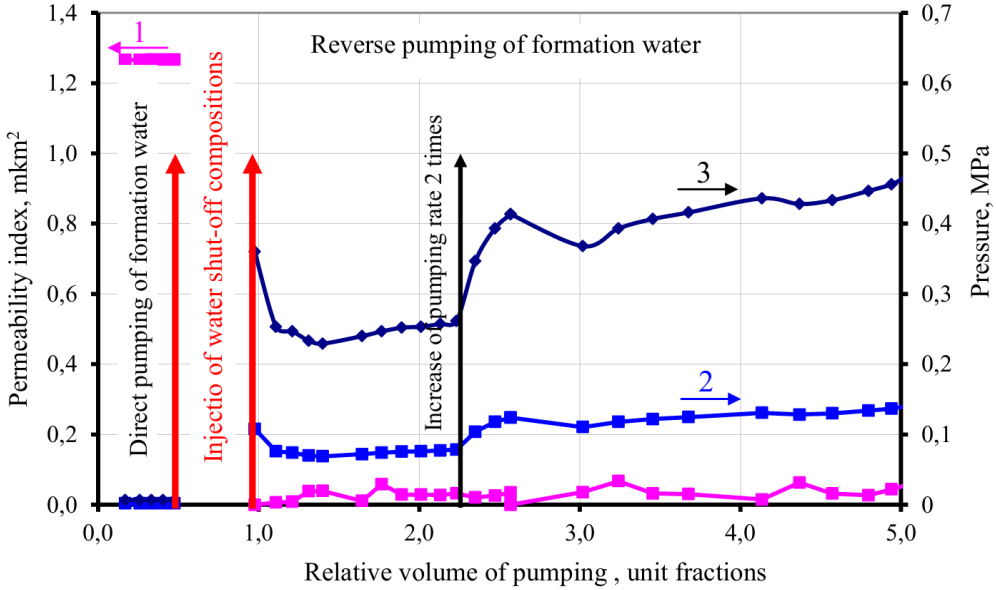

Fig. 2. Behavior of permeability, pressure gradient and pumping pressure after pumping into a water-saturated reservoir model water shut-off compositions based on “GPAN” and mineralized water (ρ = 1,15 g/cm^3):
1 – permeability factor; 2 – pumping pressure; 3 – pressure gradient

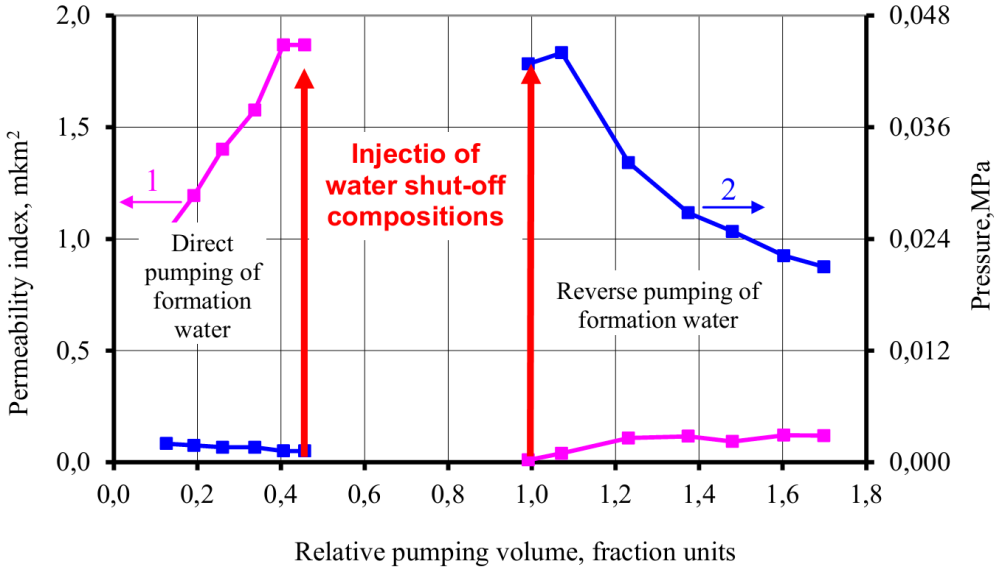

Fig. 3. Behavior of pumping pressure and permeability of water-saturated reservoir model after its treatment with 50 % water solution "OVP-1":
1 – permeability factor; 2 – pumping pressure

As it is seen from the Fig. 1 - 3, new water shut-off compositions provide qualitative shutting-off of high permeability water-saturated reservoir models [3, 5, 8]. At that the best shutting-off properties were demonstrated by water shut-off compositions based on "AKOR BN102" – permeability factor decreased per 99.7 %, pressure gradient reached 2.1 - 2.3 MPa/m. While treating models with compositions based on chemical agents "OVP-1" and "GPAN" permeability decrease made up 93.1 and 97 % respectively. Higher water isolating properties of water shut-off compositions based on "AKOR BN102" can be explained with mechanism of formation and structure of plugging materials. Thus, solutions "AKOR-BN102" refer to gel-forming compositions, making homogenous plugging material in all the volume of water shut-off compositions. In its turn, solutions based on "OVP-1" and "GPAN" refer to sludge-forming water shut-off compositions. While contacting with non-solvents they form 15 - 30 % of plugging material off the total volume of reaction mix. Each of the mentioned above types of water shut-off compositions has its advantages and disadvantages. So, much more expensive compositions based on "AKOR-BN102" should be used preferably when carrying out integrated water shut-off works with relatively small flow rate of water shut-off compositions. In its turn "OVP-1" and "GPAN' should be used when isolating extended water-saturated thicknesses or lost-circulation zones.

Carried out pilot tests of new shut-off compositions proved high efficiency of suggested technologies. Though, within the given stage of work 6 well-operations were performed [7]. Flow rate of shut-off compositions made up from 5 to 30 m^3 per one well-operation. All the works were technologically and economically efficient (Table 2).

Table 2. The results of pilot testing of new water shut-off compositions

Main component of water shut off compositions	№ well, oil field	Type of works*	Incremental oil production as of the date of 01.05.2011, t	Average production increase, t/d
"AKOR-BN102"	36, Dubrovskoye	CWEI	4891	3,4
	37, Dubrovskoye	CWEI	13027	4,5
"GPAN"	55, Malodushinskoye	CWEI	4556	2,8
	115,Yuzhno-Ostashkovichskoye	EBCF	4866	3,9
"OVP-1"	144 Yuzhno-Sosnovskoye	EBCF	17121	14,3
	57 Ostashkovichskoye	CWEI	38944	24,2

* CWEI – cutting off water encroached intervals, EBCF – elimination of behind-the-casing flow

So (Table 2), cumulative incremental production after pilot testing made up more than 83 thous. t, the durability of the effect – from 3 to 8 years. As of the date of 01.05.2011 in the wells 37, Dubrovskoye, 144 Yuzhno-Sosnovskoye and 57 Ostashkovichskoye oil fields the effect still continues. High efficiency of pilot testing let us recommend water shut-off compositions based on chemical agents "AKOR-BN102", "GPAN" and "OVP-1" for large scale industrial implementation. It should be noted, that because of financial and technical problems large capacity manufacture of chemical agent "GPAN" by JSC "Gomelskiy khimicheskiy zavod" was not organized. The whole volume of the series was limited by the experimental batch.

In the field of development of new process flow schemes and water shut-off techniques, selective water shut-off using water shut-off compositions based on chemical agents "AKOR-BN102", "GPAN" and "OVP-1" and injection of water shut-off compositions in pulse mode were tested.

The main feature of suggested technology of selective shut-off is application of water shut-off compositions of non-selective action [5, 7]. Plus, selective plugging of water-saturated intervals is provided by filtration differences of water- and oil-saturated reservoirs. Though, while pumping fluid in the reservoir due to the differences of cutoff values of pressure gradient, injectivity of each of the intervals will be proportional to the permeability. That means injected fluid will be absorbed by the most high-permeability already depleated and watercut intervals first, and to a smaller extent–by less permeable intervals, containing oil.

This technology features simplicity, low labour intensity, absence of technological operations requiring involvement of higher level specialists, small run time and cost.

For the first time technology of selective shut-off was tested in well 191g2 of Rechitskoye oil field, exposed pay bed by horizontal hole. While carrying the opera-

tions the whole set of technologies and water shut-off compositions both used previously and completely new were implemented.

They included:

– water shut-off compositions for decreasing reservoir injectivity: 10 m^3 of sodium-carboxyl-methyl cellulose solution and 6 m^3 of viscous flushing fluid based on PAA;

– sludge-forming water shut-off compositions: 90 m^3 of 50 % solution of "Lignopol" and 4.9 m^3 of solution "GPAN";

– gel-forming water shut-off compositions: 17 m^3 of solution PAA DR-9 (175 kg of commercial solution) with 1.7 m^3 $AI_2(SO_4)_3$ (0.35 t of commercial solution) and 11.8 m^3 of "AKOR-BN102" solution.

All in all 140 m^3 of chemical agent solutions were injected into uncased hole 199 m long. In such case injection pressure increased from 0 to 9 MPa.

Before water shut-off works, the well for 2 months period had been operating with liquid rate – 81.5 m^3/d and 100 % watercut. After the works performed it was put on production with liquid rate 68 t/d and watercut 83 %. Cumulative incremental production as of the date of 1.05.2011 made up 13 thousands tons of oil. The effect continues.

Carried out pilot testing of water shut-off technology in horizontal hole of well proved not only the efficiency of suggested technology of selective water shut-off in conditions of belarusian oil fields, but also the efficiency of developed water shut-off compositions based on chemical agents "GPAN" and "AKOR-BN102" [3, 5].

Following this, according to developed technology of selective shut-off using water shut-off compositions based on chemical agent "OVP-1" seven well-operations were performed. Carried out technical-economical analysis let determine, that application of new technology allows decrease the cost of well-operations in general 2 times and increase the payback from water shut-off works 3 times.

The second prospective direction in the field of implementation of new technological method of water shut-off is the technology of injection of water shut-off compositions in the mode of low- frequency pulse stimulation, tested in the conditions of Belarusian oil fields [6].

The necessity of carrying out studies in the given directions is conditioned by wide implementation in field practice of water shut-off compositions with contact mechanism of formation of plugging material, based on chemical agents: "gipan", liquid glass, "GPAN", "OVP-1", etc.

Technology of water shut-off with water shut-off compositions presents consecutive batching into reservoir solutions of sludge-forming agent and non-solvent (cross-linker) separated by flushing fluid. Quite an ordinary case- reaction of water shut-off compositions with formation water. In this case they are supposed to mix in formation and to form plugging material. The efficiency of shut-off works depends on type of agent reaction and mixing coefficient (mass transfer rate) of sludge-forming agent and

non-solvent solutions, the last of which defines the volume and the rate of formation of reaction product, blocking filtration channels.

As we know, mass transfer in porous space is complicated, that is why the sludge is formed basically on the contact line of sludge-forming and non-solvent agents.

One of the prospective directions of enhanced efficiency of works with sludge-forming water shut-off compositions should be considered the development of integrated technologies comprising different methods of stimulation.

In order to activate mass transfer in porous medium, even injection coverage, increase of volume of formed plugging material, its tightness and adhesion to the rock, the technology of injection of water shut-off compositions into reservoir in low-frequency pulse stimulation mode was suggested [1, 2, 6]. Within the frame of the given work the model of pulser B1 [9] was designed and manufactured. This device let inject technological fluid into reservoir in pulse mode with frequency 0,5 - 5 Hz and amplitude up to 12 MPa [6].

The testing of new technology was carried out in the well 45 of Dubrovskoye oil field. Functional set-up of the pulser let perform injection of technological fluids into reservoir both in pulse and non-pulse modes. That is why, in order to compare the efficiency of suggested new technology with a currently used one, 50 %-solution of chemical agent “lignopol” and mineralized water used as non-solvent was injected into reservoir in two modes. Bottomhole pressure with measuring discreteness 21 s was registered by depth electronic gauge(produced by Kuster), set in the filter under the pulser (Fig. 4).

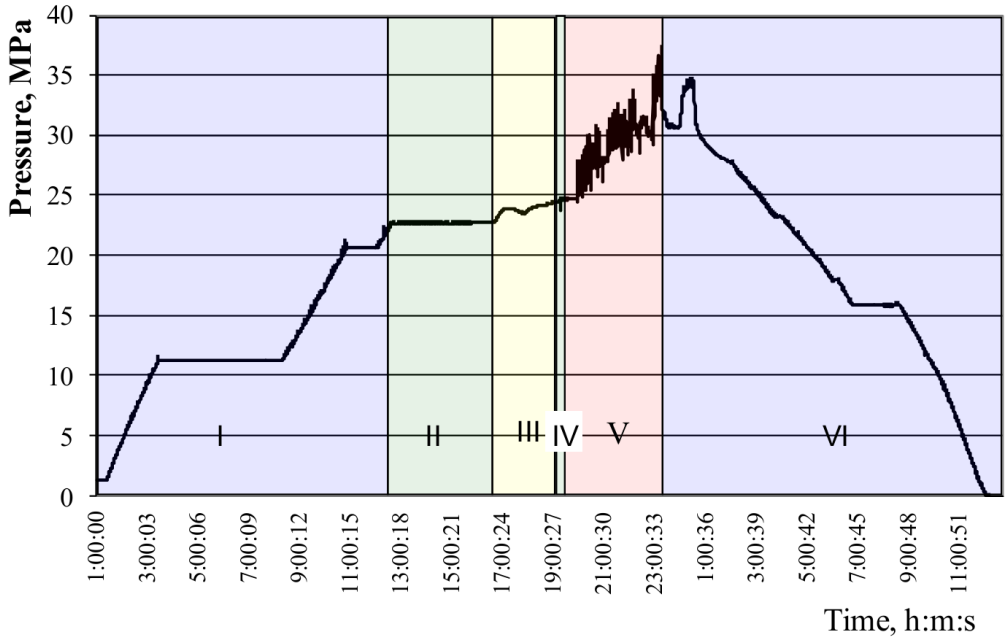

Fig. 4. Behavior of bottomhole pressure while injecting water shut-off compositions into well 45 of Dubrovskoye oil field without pulsing (section III) and in pulsing (section V) mode: sections I and VI – respectively running in and running out of the assembly; II and IV – preliminary works

As it is seen from the Fig. 4, while injecting into reservoir water shut-off compositions in non-pulse mode (section III Fig. 4) bottomhole pressure is stabilized at the level of 24 - 25 MPa, while further injection of water shut-off compositions in pulse mode the pressure rose to 38 MPa (section V Fig. 4). The given data show that in pulse injection mode mass transfer process between solutions “lignopol” and $CaCl_2$ in reservoir conditions activates.

The efficiency of suggested technology is proved by comparison of parameters of water shut-off works, performed in the single-type geo-technical conditions – wells 45 (integrated technology) and 43 (standard technology) of Dubrovskoye oil field with the standard technology. New technology not only increases the efficiency of water shut-off works, but also decreases the flow rate of water shut-off compositions 2-3 times [3].

In conclusion, it should be noted that in modern conditions of field development and resources of the majority of oil fields in Belarus it is impossible to reach high technical-economical parameters of water shut-off works without implementation of new, meeting up-to-date requirements technologies and approaches. Accumulated scientific experience, and also laboratory and testing equipment let specialists of BelNIPIneft quickly and successfully solve problems in the field of water shut-off in producer wells of the Republic of Belarus. Currently we are carrying out pilot testing of water shut-off composition of the next generation based on chemical agents “OVP-2” and different types of PAA, and also coiled tubing technologies of water shut-off works.

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