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D. Zh. Abdeli[1], A. S. Yskak[1], Adi Novriansyah[2], A. A. Taurbekova[1]

[1]Satbayev University, Almaty, Kazakhstan,
[2]Sejong University, Seoul, South Korea.
E-mail: d.abdeli@mail.ru, ardak_y78@mail.ru, anba11181@gmail.com, ainura_071@mail.ru

COMPUTER MODELING OF WATER CONNING AND WATER SHUT-OFF TECHNOLOGY IN THE BOTTOM HOLE OF OIL WELL

Abstract. This article presents the results of computer modeling of the formation of bottom water conning from the Kumkol well, as well as the results of laboratory studies evaluating the effectiveness of sodium silicate (liquid glass) and micro-cement for isolation of formation water in the production well. A technology is proposed for creating a new technology of waterproofing screen in production wells using new oil-well plugging materials based on sodium silicate and micro-cement, which allows to significantly reduce the water cut of the oil production.

Keywords: well, water conning, water shut-off treatment, sodium silicate, cross-linker, micro-cement.

Introduction. Currently, in many fields, due to the immaturity of technology of well development and well development technologies, premature watering of the produced oil occurs, reaching over 70%. This leads to a significant reduction in the oil production rate and the non-operating costs associated with the energy used to extract water and to separate it from commercial oil.

One of the main factors leading to the watering of oil wells is the flow to the bottom of the produced water through the lower perforations of the production column. As oil is extracted and pressure is lowered in the oil reservoir, the inflow to the bottom from the lower aquifer occurs as a cone through the pores and cracks of the reservoir rock, crevices formed between the rock, cement stone and production column, as well as a gradual increase in water-oil contact.

Some researchers [1] believe that the reason for high water cut of production wells is the creation of a large pressure in the reservoir, exceeding the limit value of the free water velocity and drawing the water cone into the isotropic reservoir productivity. Analysis of the application of various gel-forming compositions and compositions [1-4] showed the prospects for the development of new technologies for water isolation.

Computer modelling. A Canadian (Calgary) CMG (computer modeling program) simulator was chosen to build a model for the heterogeneous formation and evaluate the effect of the proposed waterproofing technology. Simulation at the CMG allowed the development of curves for the formation of the cone of bottom water in the borehole and to perform a comparative analysis by pumping nitrogen into the well, then a solution of sodium silicate and sodium silicate gelling solution (without nitrogen). Geological data of the formation (permeability, reservoir thickness) and formation water properties used in the model belong to the Kumkol field [5].

To simulate the formation of bottom water conning was used the STARS^{TM} software module (figure 1) [5].

According to some data from the Kumkol field (table 1), a model was created for the formation of bottom water conning in the production well. For the simulation, the data of well No. 2029 of the Jurassic horizon 2 are taken, in which the interval of the perforations is 1284-1296 m at the top of the reservoir 1268 m, the bottom is 1300 m.

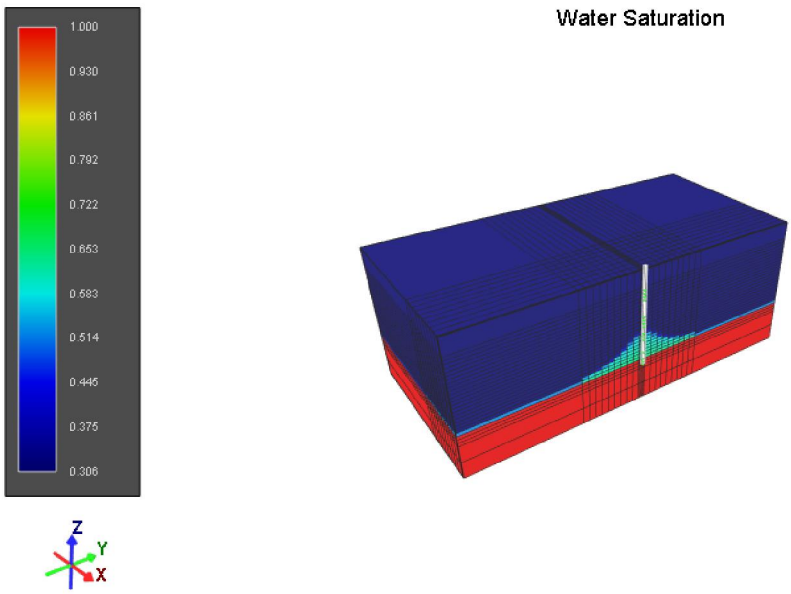


Figure 1 – Model of the formation [5]

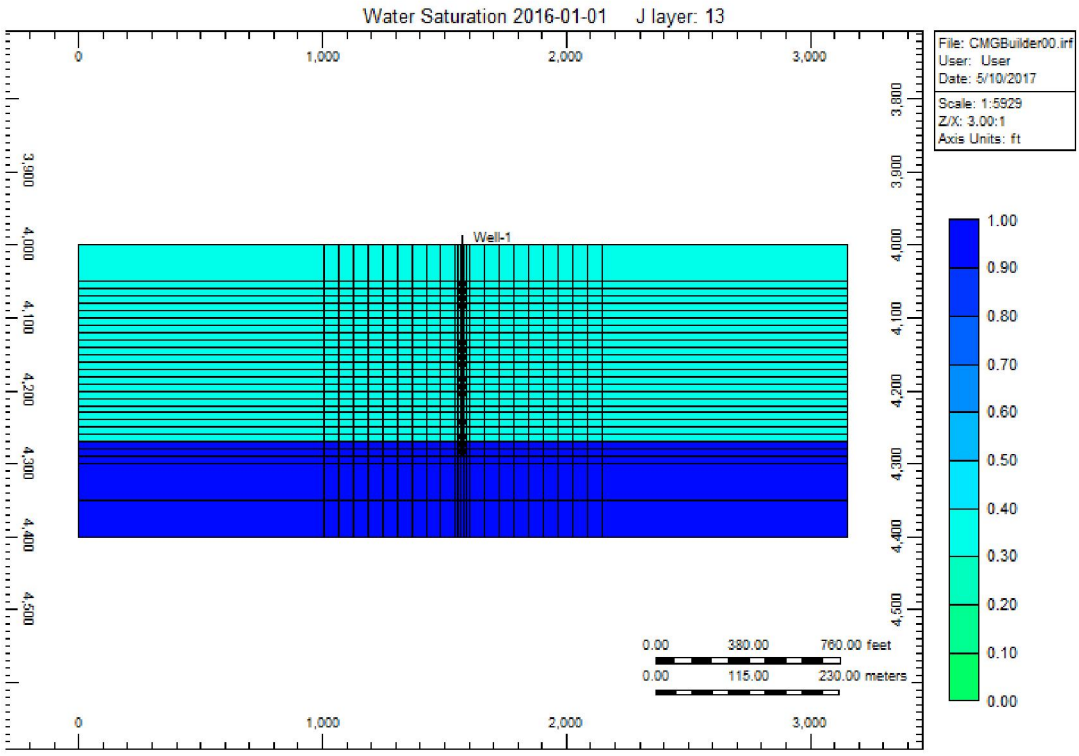


Figure 2 – The model of formation of bottom water conning at the beginning of the extraction process [5]

The beginning of the operational period 01/01/2016. Estimated operating time until 01.01.2020 (4 years). The model of bottom water conning for the current year and the estimated period is shown in figure 2.3 [5].

According to the data in table 1, a model was constructed for two water shut-off technologies for pumping nitrogen into the well, then a solution of liquid glass and pumping a solution of liquid glass without preliminary injection of nitrogen. To carry out the water shut-off technology, for the creation of a waterproofing screen, the injection of solutions is made to a pre-made perforation below the water-oil contact lines. The results of the simulation are shown in figure 6.

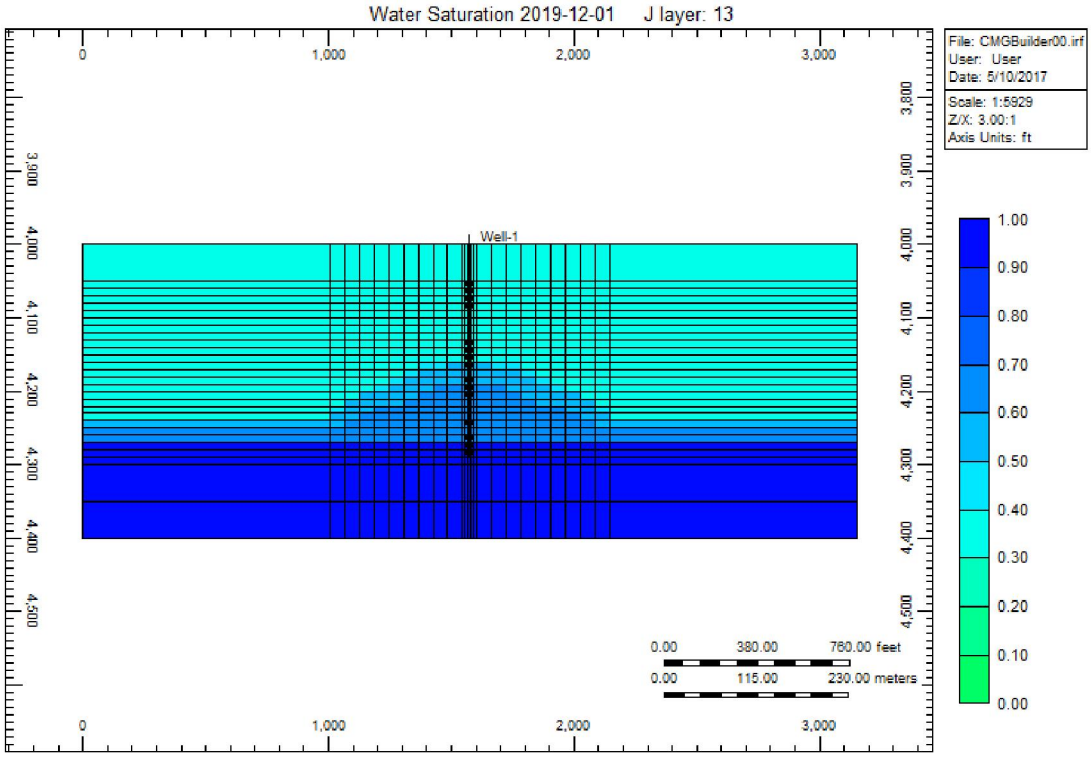


Figure 3 – Model of water cone formation after 3 years [5]

Table 1 – Physical properties of the reservoir and fluids used for simulation [5]

Reservoir properties	Fluid properties
Reservoir dimensions, ft:	*Fluid viscosities, μ ,cp,mPa·sec:*
Length, L 1000	Water (μ_w) 1
Width, W 30	Na -silicate (μ_o) 61
Thickness, H 90	Nitrogen 8760*10^{-6}
Grid definition	*Fluid densities, ρ, lbm/ft^3*
NX 25	Water (ρ_w) 62,4
NY 25	Na -silicate (ρ_o) 0.062
NZ 28	Na-silicate solution 70
Porosity 0.25	Nitrogen 0.078
Initial Pressure, P, psi 1250	*Residual saturation*
Initial Temperature, T,F(°C) 104 (40)	s_{wc} 0.25

The graph in figure 4 shows the difference in the value of the water cut in the production of the well between these technologies, where the water cut with the injection technology of the liquid glass solution without preliminary injection of nitrogen is less than with the injection of nitrogen.

Results and discussion. To isolate the inflow of bottom formation water to the bottomhole and reduce the water cut of the wells, various precipitation and gel-forming solutions of chemicals based on organosilicon, organic and inorganic compounds, naphthenic acids, polymer and foam systems, etc. are injected into the formation [6-13]. To do this, screens from various grouting materials are created through the lower perforations of the production column.

In recent years, the focus has been on the use of environmentally friendly silicate gels for the isolation of formation water. In a full literature review of the use of a silicate gel as a plugging agent and how to modify the profile of seams in the oil industry, several authors have argued [14, 15].

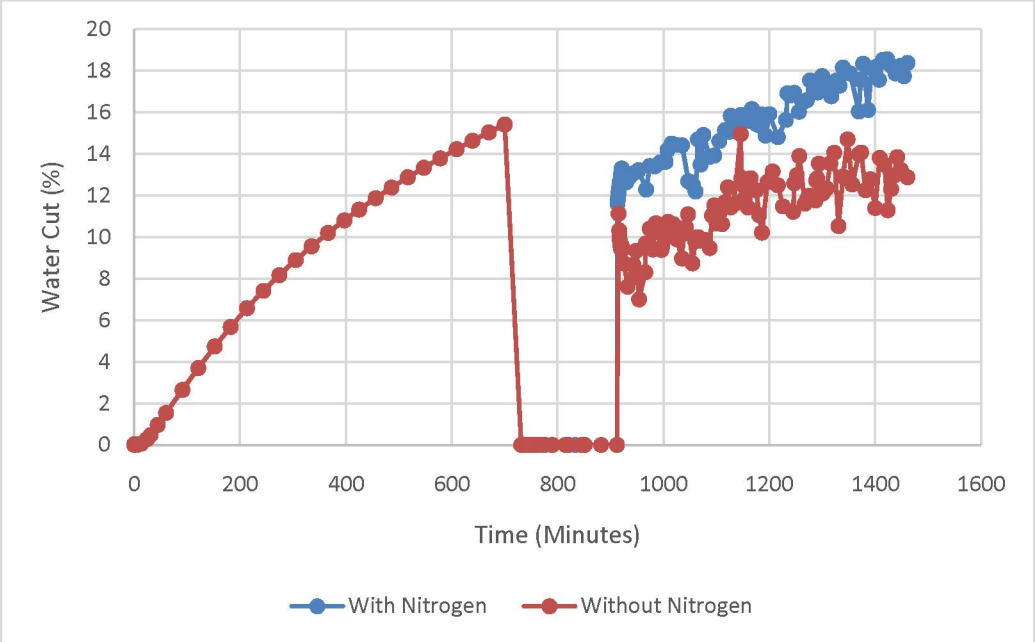


Figure 4 – Difference in the value of the water cut in the well according to the two technologies (*red line* – without pre-injection of nitrogen, *blue line* – with injection of nitrogen) [5]

The authors of Krumrine, P.H. and Boyce, S.D. [16] numerous articles and patents on the chemical composition of sodium silicate have been written, which are used in oil fields in water cut-off and cementation.

The first uses of sodium silicate together with sodium carbonate were proposed in 1922 as solid blocking agents [17, 18]. Since then, silicate-based chemicals have been widely used in various industries in several areas, such as underground mining [19], drilling [20], borehole insulation during the steam injection process [21] for deep placement and for water cut-off treatments.

The main disadvantage of existing sludge and gelling compounds is their chemical instability to the mineral salts of bottom formation water. Existing technologies of waterproofing of the bottomhole formation zone are ineffective and their efficiency is short.

Laboratory research. For laboratory studies and getting of silicate gels, we used liquid glass (Na_2SiO_3) from LLP Elmaz (Kazakhstan) and several gelling initiators (hydrochloric acid, formation water, sodium bicarbonate $NaHCO_3$), samples of the gels obtained are shown in figure 5 (*a* – with various initiators of gelling, *b* – with highly mineralized water). The silicate module n is 3.2.

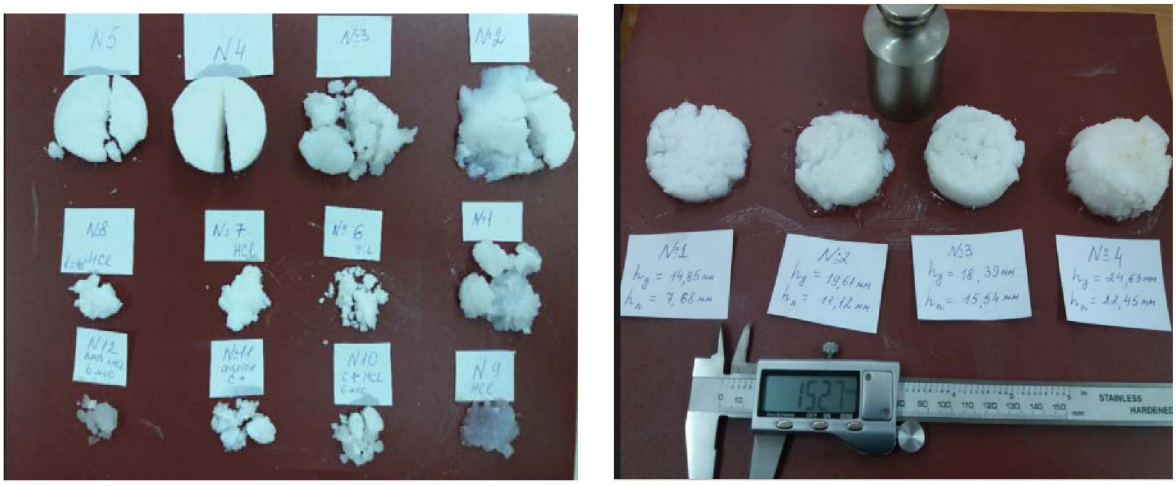
As a gel stapler, reservoir water with a density of 1,034 / cm^3 of the Kumkol field (2 objects) was taken with the following chemical composition: pH = 5.75, mineralization 67.54 g/l, Na^+ and K^+ = 16.9 g / l, Ca^+ = 3.4 g/l, Mg_2 + = 0.65 g/l, CL = 33.95 g/l of ions. As well as sodium chloride with a density of 2.161 g/cm^3, and the composition: Ba - 30 ppm; Fe - 5 ppm; K - 200 ppm; Ca - 50 ppm; SO_4 - 50 ppm; pH 5-8.

Samples were also obtained and investigated with the addition of micro-cement at different ratios of liquid glass and micro-cement (figure 6).

From these samples, the gel formed from experiment No. 4 (figure 2, *a*) with respect to the remaining samples proved to be more durable and with a small syneresis. Samples of silicate gels with different concentrations of highly mineralized water (figure 2,*b*) were tested under a load of 0.5 kg and the height variation was determined by means of a caliper, and the results are shown in table 2.

It can be seen from the experiments carried out that with a higher concentration of highly mineralized water (experiment No. 4), the height of the gel varies insignificantly with equal concentration with other concentrations.

In the proposed technology it is recommended to use micro-cement on an aqueous or silicate basis, which will allow creating a more uniform cement stone with a hydrophobic surface and with reduced brittleness.



a *b*

Figure 5 – Samples of silicate gels Na_2SiO_3:
a – with various gelling initiators; *b* – with highly mineralized water

Table 2 – Compositions of silicate gels and the results of varying the heights under the load

Substance	exp 1	exp 2	exp 3	exp 4
Formation water, *ml*	10	10	10	10
Highly mineralized water ($NaCl+H_2O$), *ml*	20	20	20	20
Concentration per 100 ml of water	100:10	100:15	100:20	100:36
Soluble liquid glass of Na_2SiO_3, *ml*	20	20	20	20
Height of the gel before and after the test under a load of 0.5 kg	14,85 7,68	19,61 11,12	18,39 15,54	24,63 22,45
Change in height Δ h, *cm*	6.97	8.49	2.85	2.18

Figure 6 – Samples with the addition of micro-cement on a silicate base at various ratios of liquid glass and micro- cement

The micro-cement is obtained by creating a vacuum in the mill's working chamber by grinding the cement raw material and precipitating the isolated micro-particles of the cement in the cyclone separator and the filters. Figure 7 shows the electron microscopic images of the initial dry cement (*a*) and the image after crushing them through a planetary crusher (*b* – after 15 minutes of aging). Due to thin micro-cement particles, oil wells easily penetrate into the pores and cracks in the bottom hole zone of the aquifer and after hardening form a waterproof screen preventing watering of the wells.

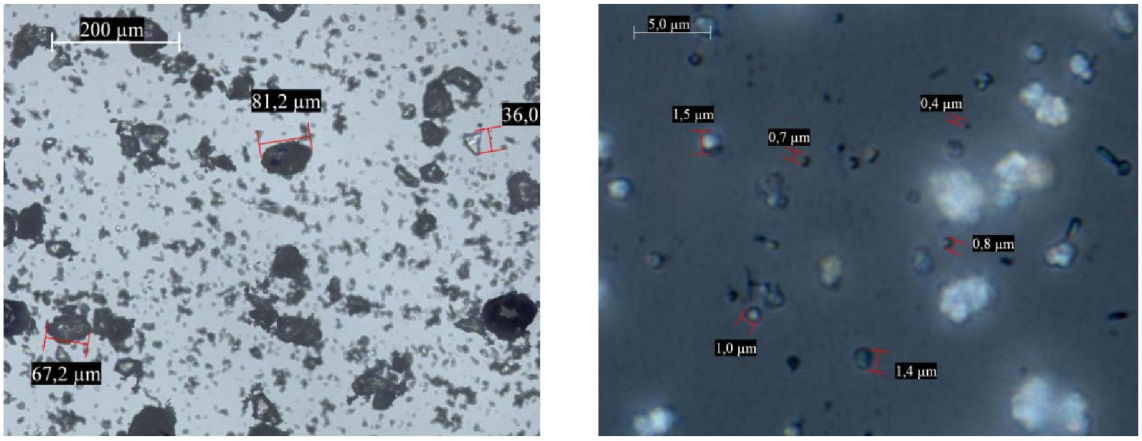


Figure 7 – Electron microscopic images of the initial dry cement (*a*) and
a picture after their crushing through a planetary crusher (*b* – after 15 minutes of aging)

From these pictures, it is possible to see the size of the cement microparticles after their crushing through a planetary crusher, which can substantially penetrate the pores and cracks in the aquifer species. Four times the experiments were carried out and the percentage of these cement particles was determined after the planetary crusher, where the particles with the size of 0.025 microns predominated in the 4th experiment (figure 8).

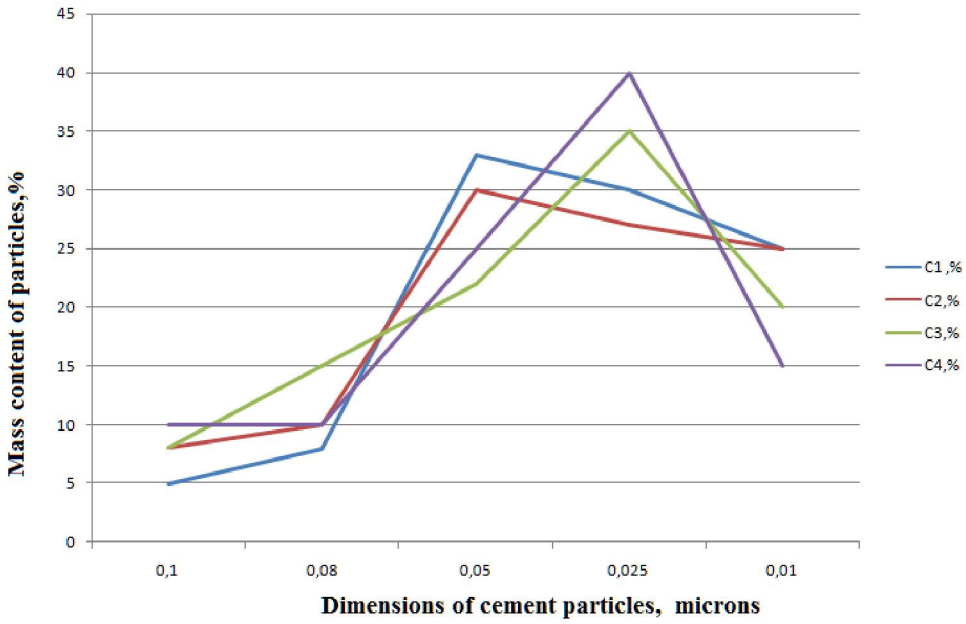


Figure 8 – Percentage of cement particles after the planetary mill

We have previously studied the gel- and sludge-forming properties of a number of oil-well materials and justified the possibility of creating a new technology for waterproofing the bottomhole of production wells using new oil-well plugging materials based on sodium silicate and micro-cement, which significantly reduces the water cut in the oil production (figure 9). Depending on the composition and properties of fluids oil-bearing and aquiferous layers, the compositions and volumes of the prewash fluid, the sediment- and gelling-working reagent, the highly disperse expanding slurry fluid mixture and the drilling fluid are selected.

The scientific novelty of the work is the establishment of the necessity of simultaneous injection of light oil and an aquifer at the perforation intervals through the perforating intervals, as a prewash fluid - fresh water, sodium silicate, fresh water, a new type of cross-linker (gellant) and micro-cement solution, which results in a reliable waterproofing screen below the bottom of wells.

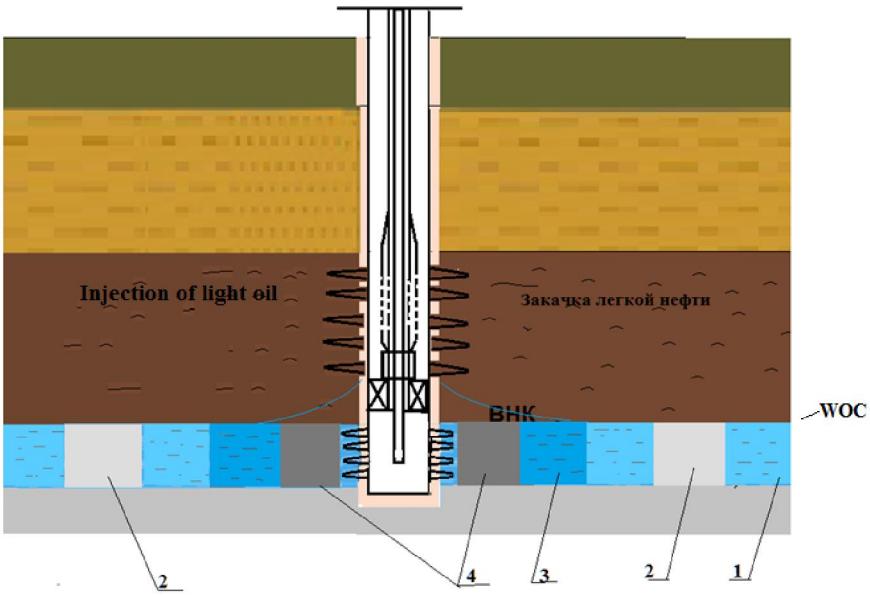


Figure 9 – *1* – fresh water; *2* – sodium silicate; *3* – highly mineralized formation water; *4* – micro-cement

In order to ensure that the planned volume of the insulating composition can be injected into the formation, it is desirable to inject a prewash fluid in front of the working agent. As a prewash fluid, fresh water or an aqueous solution of a chemical (for example sodium carbonate), which form insoluble compounds with calcium and magnesium ions, can be used to remove them from the formation water, whereby the working agent achieves a predetermined depth of penetration into the formation in a non-regulated state.

A prerequisite is simultaneous creation of equal back-up pressure in the bottomhole zone of the oil reservoir by injecting light oil or low-boiling oil components through a second tubing using an isolating two-channel packer. Under these conditions, it is prevented that the gel and precipitating substances enter the oil reservoir and reduce its permeability in the near-wellbore zone. At the mouth of the well, a double-hole wellhead setup is installed.

Conclusions. According to the research carried out, the following conclusions can be drawn:

– in this paper, simulation results show that the technology of pumping a solution of liquid glass without pre-injection of nitrogen is much more effective. It can be seen from the graph 4 that the water cut of the well with the technology without preliminary injection of nitrogen is 13%, while with the injection of nitrogen it was 18% (difference by 5%).

– creation of a reliable waterproofing screen below the water-oil contact through perforations at the bottom of the production well with the use of new plugging materials based on sodium silicate and micro-cement, allows to significantly reduce the water cut of the oil production well.

– use of micro-cement 5-10 times increases the strength of the waterproofing screen and promotes deep penetration of the solution into the formation.

Given the really established opportunity for effective use of silica gel, we should recommend the relative cheapness and working capacity of the well with this material for oil wells for further more detailed studies in order to adapt to the problem of water isolation.

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Д. Ж. Абделі[1], А. С. Ысқақ[1], Ади Новриансиях[2], А. А. Таурбекова

[1]Satbayev University, Алматы, Қазақстан,
[2]Sejong Univerity, Сеул, Оңтүстік Корея

ТАБАН СУДЫҢ КОНУСТӘРІЗДЕС БОЛУЫН КОМПЬЮТЕРЛІ МОДЕЛЬДЕУ ЖӘНЕ МҰНАЙ ҰҢҒЫЛАРЫНЫҢ ТҮБІН СУДАН ОҚШАУЛАУ ТЕХНОЛОГИЯСЫ

Аннотация. Мақалада Құмкөл кен орын ұңғысының мәліметі бойынша табан суынан пайда болатын конустың компьютерлік моделі, сонымен қатар өндіру ұңғысында қабат суын оқшаулау үшін натрий силикаты (сұйық шыны) және микроцемент қолданудың тиімдігін бағалау үшін зертханалық зерттеулер нәтижелері баяндалған.

Өндіру ұңғының түбінде суды оқшаулау үшін өндірілетін мұнайдың сулануын едәуір азайтатын натрий силикат және микроцемент негізінде жаңа тампонажды материалды қолданумен жаңа оқшаулау технолоиясы ұсынылады.

Түйін сөздер: табан су, су конусы, суды оқшаулау, натрий силикаты (шыны сұйық), гельтүзуші агент, микроцемент.

Д. Ж. Абдели[1], А. С. Ыскак[1], Ади Новриансиях[2] , А. А. Таурбекова

[1]Satbayev University, Алматы, Казахстан,
[2]Sejong Univerity, Сеул, Южная Корея

КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ КОНУСООБРАЗОВАНИЯ ПОДОШВЕННОЙ ВОДЫ И ТЕХНОЛОГИЯ ВОДОИЗОЛЯЦИИ ЗАБОЯ НЕФТЯНЫХ СКВАЖИН

Аннотация. В статье изложены результаты компьютерного моделирования процесса образования конуса подошвенной воды по данным скважины месторождения Кумколь, а также результаты лабораторных исследований по оценке эффективности применения силиката натрия (жидкое стекло) и микроцемента для изоляции пластовых вод в добывающей скважине.

Предлагается технология создания новой технологии водоизоляции забоя добывающих скважин использованием новых тампонажных материалов на основе силиката натрия и микроцемента, позволяющая существенно уменьшить обводненность добываемой нефти.

Ключевые слова: скважина, конусообразование подошвенной воды, водоизоляция, силикат натрия, гелеобразующий агент, микроцемент.

Information about authors:

Abdeli Dayrabay Zhumadilovich – Kazakh National Research Technical University named after K. I. Satpayev, doctor of Technical Sciences, Professor of department of Petroleum Engineering, scientific supervisor of scientific projects under the RK., d.abdeli@mail.ru

Yskak Ardak Sergazykyzy – Kazakh National Research Technical University named after K. I. Satpayev, master of Technical Sciences, PhD student; ardak_y78@mail.ru; https://orcid.org/0000-0002-2532-2642

Adi Novriansyah – master of technical sciences, PhD student of department of Energy and Mineral Resources, Sejong University; anba11181@gmail.com; https://orcid.org/0000-0001-6033-326X

Taurbekova Ainur Adilgazyevna – Kazakh National Research Technical University named after K. I. Satpayev, PhD student; ainura_071@mail.ru; https://orcid.org/0000-0001-5433-8347