APPLICATION OF VISCOUS GEL SOLUTIONS AND WATER SHUTOFF TECHNIQUES FOR LAYERS DURING WELL CONSTRUCTION

TATYANA NIKOLAEVNA IVANOVA[1], ALEKSANDER IVANOVICH KORSHUNOV[2], VERONIKA KVORKOVA[3], MAROS SOLDAN[4]

[1]Tchaikovsky Branch Perm National Research Polytechnic Institute, Udmurtia

[2]Federal State Budgetary Institution of Science Udmurt Federal Research Center of the Ural Branch of the RAS, Institute of Mechanics, 426000, Udmurtia

[3,4]Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Integrated Safety, Trnava, Slovak Republic

DOI: 10.17973/MMSJ.2024_11_2024027

maros.soldan@stuba.sk

Most of the oil fields are at the decline stage of development. This stage of development is characterized by a decrease in the oil production level, an increase in the water cut of the extracted fluids (up to 90%). Reducing the water cut of the produced products is facilitated by water shutoff measures. Based on the analysis of the causes of growth of water cut in wells, the most common causes of high water cut in production wells include water filtration through fractured systems and highly permeable reservoir intervals, behind-the-casing crossflows and the formation of a water cut cone. Rational control over the water cut in the produced products increases the economic efficiency of the field development and reduces the costs of treatment and utilization of extracted water. There are different approaches for solving the problem of water shutoff: creating screens and barriers using various chemical compositions, using technical means and technological methods. These technologies are classified according to the nature of the impact of the injected water-insulating mass on the permeability of the oil-saturated part of the reservoir, opened by perforation. Taking this into account, water shutoff technologies are divided into selective and non-selective ones. The use of rigid gels is one of the methods of water shutoff in the near-well area. Gels can be injected selectively into the formation using coiled tubing (CT) and a packer. In case of absence of interlayer crossflows, an injection of a rigid gel into a watered-out formation can prevent unwanted water from penetration into the well.

Keywords

fault, injection well, producing well, water shut-off technologies, water-bearing horizon

INTRODUCTION

Current period of oil production results from the rapid transition of the main production facilities to the final stage of development [Savenok 2020], the features of which include a decrease in the rate of production, low production rates and high water cut [Moroz 2020]. Premature water breakthroughs and resulting high water cut are one of the problems that arise during development of old fields [Afanasyev 2012, Kuznetsov 2020]. Reservoir water shutoff is an urgent task of oil production [Baranov 2017].

Limiting water inflow into oil wells is carried out by fulfillment of water shutoff works [Dzhus 2020, Dodok 2017, Kalentev 2017, Hu 2022]. Their main purpose is to insulate the water flow paths into the well in order to reduce the water cut of the produced fluid [Andrusyak 2017]. The main method of carrying out water shutoff works in oil wells is the injection of chemicals capable of filtering into a porous environment and plugging the water flow paths in a well [Lao 2016]. The relevance of solving the problem of limiting water inflows and improving the quality of measures, aimed at these goals, increases [Li 2019].

Thus, studying and rationalizing water shutoff techniques by means of selective properties of gelling agent is relevant task [Velychkovych 2020, Saga 2019, Wang 2017].

The most common causes of high water cut in producing wells include water filtration through fractured systems and highly permeable (washed out) reservoir intervals, behind-the-casing crossflows and the formation of a water cut cone [Xing 2014, Pivarciova 2019]. This process is typical for fields with a high degree of heterogeneity, where high-permeability interlayers are being watered at a faster rate [Boloz 2020, Barnik 2019]. Moreover, water breakthrough to bottom-holes of wells and their complete watering occurs long before the achievement of potentially possible oil withdrawal rate [Wang 2016]. This dramatically reduces the rate of current oil production, the efficiency of the reservoir pressure maintenance system [Strzalkowski 2019]. At the same time, it increases the load on the oil gathering and treatment systems [Jami 2019] and leads to other negative consequences [Qazizada 2018]. Premature watering out leads not only to blocking of part of the oil in the reservoir and its ultimate loss, but also to a significant increase in oil production costs [Qazizada 2016, Ivanova 2020].

Heterogeneity of reservoirs is the one of significant causes for the intensive water cut of oil and gas wells along the strike area and thickness of the reservoir [Liang 2016]. Due to the heterogeneity of productive layer wells are often watered non-uniformly [Li 2015]. Earlier watering out of separate layers or interlayers creates negative conditions for oil production [Raimbay 2017, Han 2017].

High quality division of layers is considered one of the most significant and challenging tasks in completing well construction [Rybar 2017]. When the productive part of the reservoir is not closed, it leads to disturbance of balance, which has been forming over long-lasting geological periods [Kleczek, 2016, Hortobagyi 2021]. Regardless to the quality of the separation of the layers, natural isolation of the layers will not be achieved [Flegner 2015, Li 2014].

REVIEW OF EXISTING TYPES OF WATER SHUTOFF TECHNIQUES

1.1 Causes of well watering

The produced water is divided into two types. The first type includes water that comes from injection wells or from active aquifers that contribute to the displacement of oil from the reservoir. It enters a well in a volume less than the limiting one, which corresponds to the critical oil-water ratio. The oil-water ratio (OWR) is the ratio of water flow rate to oil flow rate, and it is determined by the economy. The second type includes water that enters the well and is produced with or without oil in a volume, which is not sufficient to cover the costs associated with its utilization - i.e., the volume of water exceeds the economic limit determined by the critical OWR. The causes of the intrusion of water of the second type vary in each separate well. Table 1 summarizes them into ten basic situations.

Table 1. Main types of excessive water inflows

Problems	Causes	Solutions for	
		Vertical wells	*Horizontal wells*
Leakages in casing, tubing or packer	- well stock aging; - technological causes; - corrosion	- use of insulating fluids, plugs, cement bridges and packers; - use of plasters.	
Behind the casing crossflows	- low quality of cement stone; - cavities in the annulus	- use of insulating fluids (injection of high-strength cement or resin polymers in the annulus or injection of gel-based liquids of smaller strength intended to prevent water inflow in annular space)	
Movement of oil-water contact (OWC)	- low vertical permeability	- plugging of lower perforation holes by means of mechanical systems.	- additional sidetracking.
Watered out interlayer without crossflows	- presence of highly permeable interlayer, limited by waterproof layers, lying under and upper	- use of rigid insulating fluids or mechanical insulators.	- this problem does not occur in horizontal wells which penetrate only one productive horizon
Fracturing or faults between injection well and producing well	- presence of fractured or fractured-porous formations and branched fracture systems	- injection of gels; - water shutoff (it is the best way to solve this problem	
Fractures or faults, connecting oil-saturated and water-saturated layers	- presence of system of fractures, which cross water layer	- treatment of fractures with gelling agents (most successful when there is no oil inflow in fractures) - plugging of fractures in the near-well area (in case of localized fracture system)	
Coning and cresting	- OWC is near lower perforation holes - high vertical permeability	- injection of big volumes of gel above OWC; - sidetracking near formation top.	- use of insulation in the near-well area along sufficient length both in upward and downward directions
Low areal sweep efficiency	- areal heterogeneity of permeability - close location to water source	- deflection of flow of injected water - infill drilling	- insulation of separate parts of the well
Gravity-segregated layer	**gravitational separation of fluid**	**- sidetracking; - foam flooding**	**creation of the second sidetrack, located closer to the top of the bed**
Watered-out layer with crossflows	- highly permeable interlayers not separated by impermeable bridges	- injection of gel deep into thin watered interlayer; - horizontal drilling	this problem does not occur in horizontal wells, which penetrate the one interlayer

Problems	Causes	Solutions for	
		Vertical wells	*Horizontal wells*
Leakages in casing, tubing or packer	- well stock aging; - technological causes; - corrosion.	- use of insulating fluids, plugs, cement bridges and packers; - use of plasters.	
Behind the casing crossflows	- low quality of cement stone; - cavities in the annulus.	- use of insulating fluids (injection of high-strength cement or resin polymers in the annulus or injection of gel-based liquids of smaller strength intended to prevent water inflow in annular space)	

1.1.1 Leakages in casing, tubing or packer

Leakages in casing, tubing or packer cause penetration of water from aquifers into a well (Fig. 1).

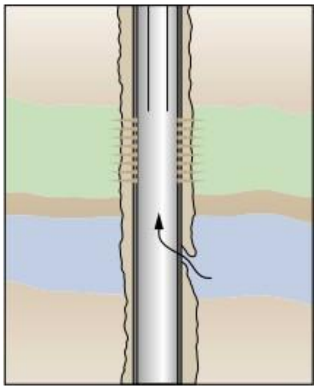

Figure 1. Leakages in casing, tubing or packer

The problem definition and solution is highly dependent on the well design. To diagnose the problem, it may be quite sufficient to carry out the simplest production logging - using a density meter, thermometer and spinner. More complex wells may require the use of well flow log (WFL) and three-phase holdup log (TPHL) methods (determination of water inflow profile and volumetric content of individual phases in a multiphase flow) using a phase volumetric flow meter. Devices with electrical samplers, such as the FlowView, can measure small amounts of water in the total fluid flow. The standard solution is the pumping of insulating fluids and mechanical insulation using plugs, cement bridges and packers. Patches can also be used. The main method for solving this type of problem is the use of cheap downhole water shutoff technologies.

1.1.2 Behind the casing crossflows

Low quality of cement stone can lead to formation of connection between aquifers and oil-saturated strata (Fig. 2). The presence of such channels allows water to flow from outer annulus into inner annulus. The second cause is the occurrence of "cavities" in the outer annulus due to sand production. Thermometry or Oxygen Activation Logging WFL for identifying behind-the-casing flows can identify these water inflows. The main solution is the use of insulating fluids, for example, injection of high-strength cement or resinous polymers into the annulus, or weaker gel-based fluids injected into the formation to stop the flow into the annulus. An accurate supply of chemicals is especially important, which is usually accomplished using coiled tubing units.

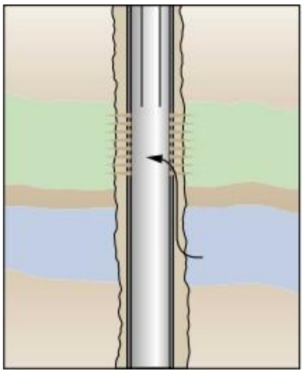

Figure 2. Behind-the-casing flows

1.1.3 Movement of oil-water contact (OWC)

The constant upward movement of the OWC into the perforation zone of the well during operation in a water drive mode can lead to an unwanted water breakthrough (Fig. 3). This phenomenon occurs if vertical permeability is very low. Since the inflow area (drainage zone) is large, and the upward velocity of the OWC is small, the OWC rise can also occur at very low natural vertical permeability (less than 0.01 mD).

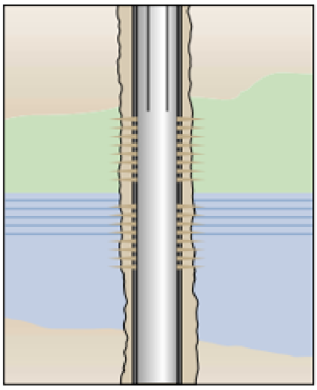

Figure 3. OWC movement

In wells with higher vertical permeability (Kw > 0.01 Kg), coning and other problems discussed below are more common. In fact, the OWC movement can be considered a special case of coning, but the tendency to coning is so small that water shutoff in the near-well zone can be effective. The diagnostics of this problem cannot be based only on the fact that water is detected in the lower perforation channels, since this phenomenon can be caused by other reasons. In vertical wells, this problem can be solved by plugging the lower perforation holes using mechanical systems such as cement bridges and wireline packer bridges. The need for repeated treatment arises when the OWC moves above the plug. For vertical wells, this problem is the first example in our classification, when the cause of excess water production is not localized in the near-wellbore zone and can spread beyond its boundaries.

1.1.4 Watered out interlayer without crossflows

In horizontal wells, any downhole or near-well stimulation must propagate quite far from the watered interlayer in upward or downward direction to reduce horizontal water flow near the treatment area and to delay subsequent water breakthrough. An alternative solution can be sidetracking if the oil-water ratio exceeds the economic limit. Water-cut interlayer without internal crossflows. A widespread problem in the joint operation of several reservoirs is water breakthrough through a highly permeable reservoir bounded at the top and bottom by cap rocks (Fig. 4). In this case, the source of water can be active edge water or an injection well. Most often watered out layer has the biggest permeability. If there is no internal crossflows this problem can be easily solved by application of rigid insulating compositions or mechanical insulators in injection well or producing well. The choice between injection of insulating liquid (usually with the use of coiled tubing unit) or use of mechanical insulating systems depends on interlayer having been watered. Efficient selective liquids, discussed below, can be applied in this case to avoid additional expenses connected with logging and selective pumping. The absence of crossflows in the formation depends on the presence of a confining layer along the entire length of the formation. This problem does not occur in horizontal wells that penetrate only one productive horizon. Problems arising from the joint operation of several reservoirs with a directional well are solved in the same way as in a vertical one.

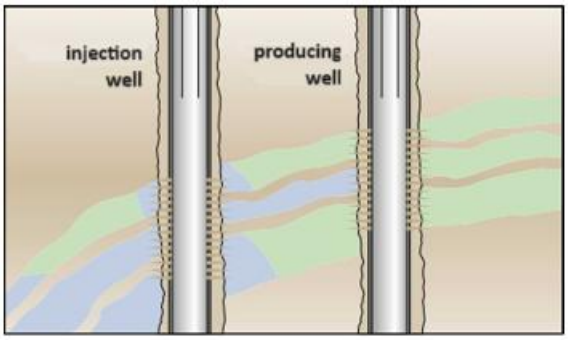

Figure 4. Watered out interlayer without internal crossflows

1.1.5 Fracturing or faults between injection well and producing well

During flooding of fractured or fractured-porous strata, the breakthrough of injected water in producing wells can occur (Fig. 5). Most often this happens if there is branched fracture system. It can be proven by the use of interwell tracers and pressure transient analysis. 6 Radioactive isotope logging can be used to give quantitative evaluation of fracture volume. This information is used later to develop the design of the treatment required. Injection of gels can reduce the amount of water produced without any unwanted effect on oil production. Injection of crosslinked gels can require significant pressure drawdown to displace them from the annulus into the formation, as they poorly penetrate through porous blocks and flow selectively along fractures. The best solution to this problem is water shutoff. In wells with large fractures or faults, an extremely high loss of drilling fluid is observed. If there is a suspicion of conductive faults and associated fracture systems, the use of flowable gels while drilling can help in solving both drilling problems and subsequent water production and low sweep efficiency. This is especially helpful in reservoirs with low permeability blocks. The same kind of problems can occur in horizontal wells, when they open one or more conductive faults or a system of connected fractures.

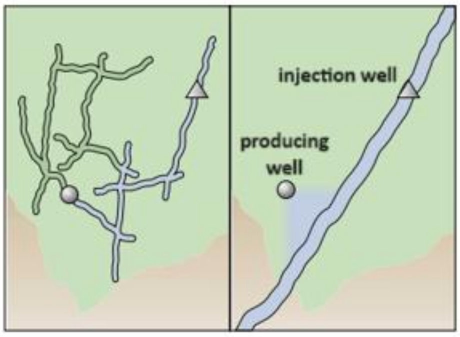

Figure 5. Fractures or faults between injection and producing wells

1.1.6 Fractures or faults, connecting oil-saturated and water saturated layers

Water can penetrate through system of fractures, which go through underlying aquifer (Fig. 6). Such fractures can be treated with gel solutions. This type of treatment is most successful when there is no oil flow in fractures. Pumping volume should be significant to plug the fractures, located far from the well.

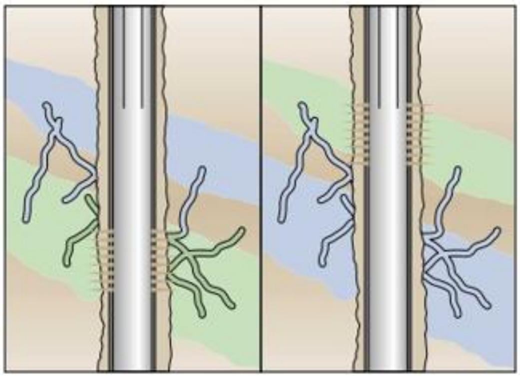

Figure 6. Fractures or faults, propagating through an aquifer (vertical well)

During treatment calculation, an engineer faces three problems. First, it is hard to determine sufficient pumping volume as volume of fractures is unknown. Second, pumped gel can plug productive fractures. In this case, well flushing with spacer fluid is required to save the productivity of near-well area. Third, when non-hardening gel composition is pumped, the treatment must be fulfilled perfectly to prevent from gel return after treatment. If there is localized fracture system, the right decision is its plugging in the near-well zone, especially when the well is cased and cemented. Similar decrease in well productivity can be observed during hydraulic fracturing, when the fracture propagates in aquifer. Nevertheless, if there are problems in such situations, the cause of water breakthrough and surrounding environment are usually known, so the solutions like use of insulating fluids can be found much easier.

In many carbonate formations, fractures are steeply dipping and fractured zones are divided by large blocks, which is typical for dense dolomite layers. Thus, the probability of encountering these fractures by a vertical well is very low. However, such fractures are often observed in horizontal wells, usually water penetrates through conductive faults or fractures, which propagate through aquifer (Fig. 7). As it was mentioned above, injection of rigid gels can help to solve such problems.

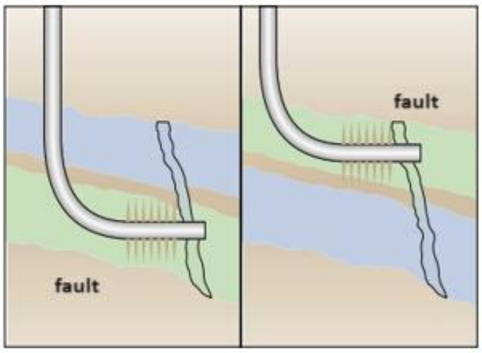

Figure 7. Fractures or faults, which cross water-saturated layer (horizontal well)

1.1.7 Formation of coning and cresting

Coning occurs in vertical wells, where OWC is located near lower perforation holes in layers with relatively high vertical permeability (Fig. 8). Maximum flow rate, under which this phenomenon does not occur, is called critical coning rate. In economic terms, it is too low. One approach, sometimes suggested for no particular reason, is to inject the gel layer above the OWC. Such measure rarely prevents from coning and requires pumping of too large volume of gel to reach a sufficient decrease in WOR. For example, efficient radius of gel injection should be at least 15 m to double the critical coning rate.

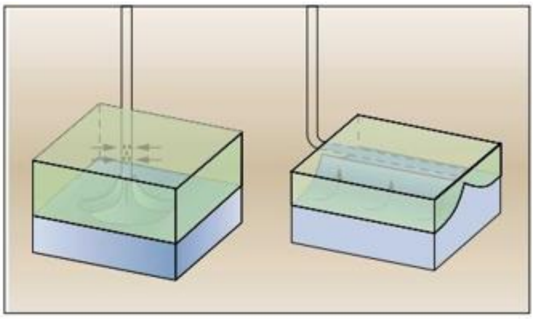

Figure 8. Coning and cresting

As practical experience shows, injection of gel so deep into the layer is hard to carry out from the economical side. Injection of smaller volumes of gel usually leads to rapid water breakthrough excluding the cases when gel pad is connected with clay bed. Drilling of one or several horizontal sidetracks near layer top is a good alternative to injection of gel. This measure helps to increase the distance to OWC and leads to a decrease in coning effect in case of operation under lowered pressure drawdown. As for horizontal wells, the phenomenon of water breakthrough is called cresting. When OWC moves upward, cresting can be decelerated if water shutoff measures are fulfilled in the near-well zone, which spreads upon large distance up and down the wellbore.

1.1.8 Low areal sweep efficiency

The movement of edge water or water from injection wells often leads to low areal sweep efficiency (Fig. 9). Areal heterogeneity of permeability is the main cause of this problem, which is shown best in the arm-shaped hydrocarbon deposits in sandstones. The solution of this problem is in deviation of flow of injected water away from already washed pore space. It requires large pumping volume or long-lasting polymer flooding. Both proposed solutions usually turn out to be economically irrational. Infill drilling is often successfully used to improve sweep efficiency in such cases, though drilling of sidetracks is more cost-efficient method to involve unwashed blocks into development. Horizontal wellbore can open formation zones with different permeability and pressure, which results in low areal sweep efficiency. On the other hand, water breakthrough can happen only in the one of borehole sections due to its close location to a water source. In both cases, water inflow in the borehole can be controlled by means of insulation of its separate sections.

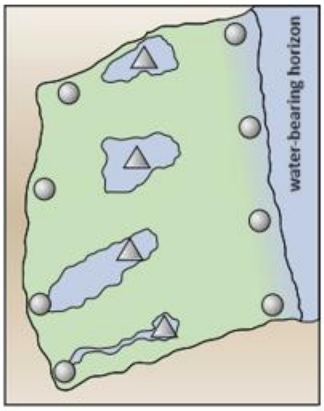

Figure 9. Low areal sweep efficiency

1.1.9 Gravity-segregated layer

In very thick layers with high vertical permeability, gravitational separation can cause unwanted water inflow in oil-producing well (Fig. 10). Edge water or water, pumped through injection wells during flooding mostly penetrates into lower part of production zone, leaving upper part of the layer unwashed. The situation gets worse if mobility ratio is unfavorable.

The problem gets even more complex in sedimentary layers stratified by the characteristic texture size (grains or pores) from the floor to the top so that permeability drops with decreasing depth. In this case, the viscous effects together with gravity separation lead to the fact that the flow of the displacement fluid moves along the floor of the formation. Any treatment of water injection well, aimed at insulation of lower perforation holes, gives unimpressive results in terms of increasing the sweep efficiency because with distance from the well gravitational separation starts to prevail again. As for producing wells, local coning is observed, therefore, as in case, described above, obtaining long-term effects from gel treatment is unlikely. Sidetracking can be efficient method to reach unwashed blocks of oil. Foam flooding can also improve vertical sweep efficiency. In case of horizontal wells, gravitational separation can occur, when borehole is located close to the floor of the bed or when flow rate exceeds critical coning rate.

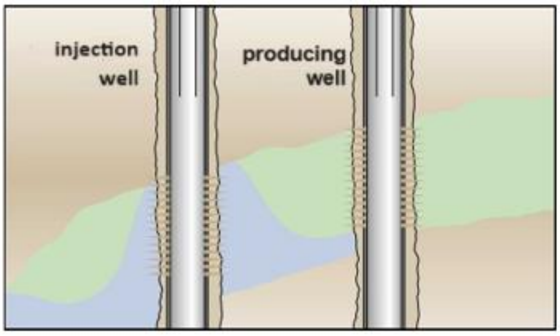

Figure 10. Gravitational separation of fluids in a well

2.1.10 Watered out layer with interlayer crossflows

Crossflows occur in highly permeable interlayers which are not separated by impermeable barriers (Fig. 11). Water inflow into the well through a highly permeable watered interlayer with crossflows is similar to the problem of a watered interlayer without crossflows; the only difference is that there is no barrier that prevents crossflows to adjacent layers.

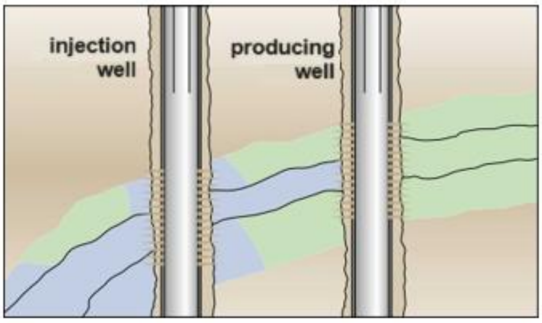

Figure 11. Watered interlayer with interlayer crossflows

1.2 Diagnostics of sources of water trouble

An understanding of the emerging problems is necessary to effectively control water production. The way to eliminate the source of excess watering is diagnostics, which allows one to determine the type of arising problem. There are three main directions in well diagnostics of water inflows: selection of candidate wells, determination of the type of problem and determination of the profile of water inflow into the well. The production history data also contain enough information for diagnostics [Baranov 2017].

There are several ways to determine the source of excess water cut, which use information about changes in water-oil ratio, production dynamics and log data:

1. Graph of the logarithm of OWR from accumulated production

It allows one to determine the expected cumulative production in case if no measures are taken to limit water production.

2. Production history graph

The dependences of oil and water flow rates on time are plotted in logarithmic coordinates of this graph. In good candidate wells, water production increases and oil production decreases at approximately the same time.

3. Analysis of flow rate decline curves

This graph plots dependence of oil production rates on cumulative production in semi-logarithmic coordinates. An accelerated decrease in oil production rate can serve as an indicator not only of the oncoming water cut, but also a significant drop in pressure as a result of formation depletion or a decrease in the hydraulic conductivity of the near-well zone.

4. Graphic diagnostics of water cut development

A graph plotting OWR dependence on time in logarithm coordinates can be useful in identifying a specific type of water cut problem when compared with curves from known models.

5. Analysis of well shutdowns and limitations of their fluid flow rates

Analyzing OWR fluctuations can be helpful in determining the type of problem.

6. NODAL system analysis

NODAL analysis is a standard method for modeling of well behavior and it usually consists of the following stages: model building, geology, reservoir pressure, selection of correlations for calculating of multiphase flows in inclined pipes, crossflows during well shutdown and in operation.

7. Well logs of the inflow profile

State-of-the-art inflow profile diagrams allow localization of the places of water intrusion in the wellbore and help to determine the volumetric content of phases.

A correct understanding of the causes of excess water inflows leads to an efficient solution of emerging problems. Rational control over the water cut of the produced fluids increases the profitability of the field development, and also reduces the costs of produced water processing and utilizing.
With aging of well stock, the oil/water ratio (OWR) increases with the process of production (A) due to an increase in the amount of produced water. Eventually, the cost of water processing reaches the cost of the oil produced, and the OWR passes "economic limit" (B). Water-cut control methods and techniques reduce the amount of water produced from the well (C), thereby allowing economically profitable oil production to continue. Controlling water cut leads to an increase in economically achievable well output (D).

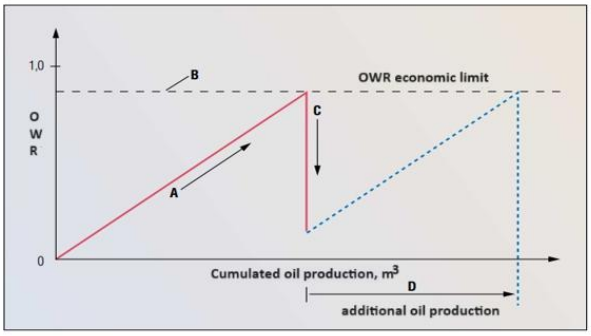

Figure 12. Controlling water cut to increase well productivity and potential reserves growth

1.3 Geophysical methods for determining the source of water cut

When an inflow, received during formation testing, does not correspond to the nature of saturation, or a mixed inflow (oil with water, gas with water and oil) it is necessary to fulfill reinterpretation of the whole available geological field material. Saturation parameter and oil saturation factor are determined according to the geophysical studies of the section and available petrophysical correlations.
The methods, mentioned above, make it possible to show whether the water inflow goes from the perforation interval or whether it is associated with a production casing leak. Interlayer crossflows, intervals of behind-the-casing circulation and effective working thickness inside it are determined by high-precision thermometry methods, impulse neutron-neutron logging. According to the acoustic cement meter (ACM) data at two frequencies (20 - 25 and 6 - 8 kHz), it is possible to measure the quality of cementing of the production casing and estimate the interval of the behind-the-casing circulation and the flow rate. All these works are carried out by the contractor services on the basis of existing regulatory and instruction documents.
Taking into account the mechanism of formation of water-insulating masses and physicochemical regularities of impact on the host medium, five groups of chemical reagents used for water shutoff can be distinguished (Tab. 2).

Table 2. Five groups of chemical reagents

Chemical reagents used for water shutoff	Self-hardening
	Gelling
	Residue-forming
	Water repellents
	Foams and emulsions

Self-hardening compositions are chemical reagents that form a strong condensation-crystallization spatial structure throughout the volume of the material after hardening. In other words, they form the structure, which is soluble in oil and insoluble in an aqueous medium (organic - synthetic resins of various types, inorganic - cements). In common, such reagents are non-selective without the use of special technical means and technological methods.
Gelling compositions are chemical reagents of inorganic and organic nature, leading to the formation of spatial gel-like systems with water or a non-aqueous dispersion medium. The main chemical reagents for the formation of gel structures are shown in Table 3.

Table 3. Gelling Chemicals

Name	***Chemical reagents***
Polymers of acrylic acids and their derivatives	Polyacrylamides and Copolymers of Acrylamide Hydrolyzed Polyacrylonitrile
Monomer compounds	Acrylamide Styrene
Cellulose derivatives	Carboxymethyl Cellulose Oxyethylated Cellulose Methyl Cellulose Lignosulfonate
Biopolymers	Xanthan Scleroglucan Emulsan BP-92

The use of residue-forming chemical reagents leads to the precipitation of insoluble residue (solid or gel-like type) in water-saturated zones. The formation of a precipitate can occur both during the interaction of the reagents with each other and in case of contact with water and salts dissolved in it.
Water repellents are reagents, the use of which is based on the hydrophobization of the surface of the bottomhole zone rocks, which leads to a decrease in its water saturation. In this case, surfactants, aerated liquids and other chemical hydrophobizing reagents are used.
Foam systems are the systems consisting of liquid and air, they are formed when gases are pumped into liquids or as a result of the interaction of chemicals. The injection of foam systems into the pore space ensures blocking of the paths of water movement due to the adhesion of gas bubbles to the surface of the water-conducting channels and the formation of films from colloidal dispersed compounds.
Emulsions are systems consisting of hydrocarbon and water phases, stabilized with an emulsifier. They are mainly used for the treatment of injection wells. This subset of chemical reagents is rather conditioned, since many substances can form different types of water-insulating masses, depending on the specific conditions. Moreover, most of them are now used not in pure form, but as part of various compositions.
To limit water inflows, it was proposed to use a significant volume of chemical reagents, however, only a few were actually applied in practice. Although cement is a non-selective and non-filtering material, it is the most widely used method for water shutoff works. This is primarily connected to its presence in the fields, availability and low cost.
As for examples of improper use of a cement slurry, it worth mentioning that the shutoff of interlayer crossflows is not always effective, as in the presence of a difference in reservoir pressure, water breaks through the cement slurry even when it has not yet hardened. Part of the cement slurry, which enters the aquifer, spreads through it along drainage channels.
If it is not possible to locate the watered interval, or if aquifers are located throughout the filter interval, it is not recommended to install a packer and temporarily introduce blocking fluids. In this case, it is effective to use methods of injection of compositions of selective nature.
Among the selected compositions, there are two main groups of selective materials:

additional oil

The ones, that form a plugging mass (gel, solid material, residue) as a result of the interaction of the coagulation of the grout material with polyvalent ions or other coagulants contained in the formation water or in the previously injected fluid.

The ones, that form a solid substance or gel under action of water, regardless of its ionic composition. This hardening is based on hydrolysis reactions and further polycondensation (crosslinking) of hydrolysis products. Compositions of the first group are water solutions of acrylic polymers (hypane, acrylamide, polyacrylamide (PAA) with gelling agents), synthetic latexes (rubber solutions), compositions based on inorganic salts (liquid glass, aluminosilicates).

The second group of compositions includes chemical compounds, which harden on the base of hydrolysis and polycondensation reactions of hydrolysis products.

Selective isolation of water inflow involves: shutdown of depleted (watered out) formation intervals; elimination of interlayer and behind-the-casing flows, bottom waters shutoff; elimination of leaks in casing strings, building up a cement ring behind the casing; insulation of watered fractured reservoir intervals, including carbonate ones, as well as selective isolation of reservoirs (limitation of produced water).

CONCLUSIONS

Today, the combating water inflows includes a list of various technologies - from classical cementing to the use of two-packer assemblies and the latest chemicals.

The use of rigid gels is one of the methods of water shutoff in the near-well area. Unlike cement, gel can be squeezed into the target formation to give complete shutoff or to reach contact with shale barriers. Gel has another operational advantage to cement, as it can be jetted rather than drilled out of the wellbore. The gel is usually based on crosslinked polymers such as MaraSEAL and OrganoSEAL-R. These reagents are easy to mix and they maintain performance characteristics for a long time. They are usually used for injection into the formation and solving water cut problems, associated with behind-the-casing crossflows and watered out interlayers without crossflows. Gels can be injected selectively into the formation using CT and a packer. Another method for solving such problems is the use of flowable gels. They are injected into small faults or fractures but only penetrate into formations with permeabilities greater than 5 Darcy. Large volumes (160 to 1600 m3) of these inexpensive fluids often successfully shut off extensive fracture systems surrounding injecting or producing wells. Like rigid gels, reagents such as Marcit and OrganoSEAL-F are crosslinked polymers. They are easy to mix, they remain liquid for three days and can be pumped through filters installed during well completion. For the treatment of the porous rock skeleton in the near-well zone, “smart” or selective fluids have been developed. These fluids are mixtures of polymers and surfactants. Treatment with these substances, also called "relative phase permeability modifiers", creates a stable gel-like material that stops the movement of water in the flooded layers, but does not interfere with the movement of oil. In some cases, these reagents allow low cost selective treatment to be performed by simple bullheading them into the formation.

ACKNOWLEDGMENTS

This publication was created thanks to the support of the project KEGA No. 004TU Z-4/2024: Implementation of progressive methods of education in professional subjects in the field of mechanical engineering and industrial robotics.

REFERENCES

[Afanasyev 2012] Afanasyev, V.A. Optimization of well assemblies and well pump equipment of dual completion. Engineering Practice, 2012, No 2, pp. 36-38.

[Andrusyak 2017] Andrusyak, A., et al. Developing a method for the assessment of axial load in arbitrary cross-sections of the column of pumping rods. Eastern-European Journal of Enterprise Technologies, 2017, Vol. 1, No. 7, pp. 32-37 DOI: 10.15587/17294061.2017.92860.

[Baranov 2017] Baranov M.N., et al. Constructing and calculating of multistage sucker rod string according to reduced stress. Acta Montanistica Slovaca, 2017, Vol. 22, No. 2, pp. 107-115.

[Barnik 2019] Barnik, F., et al. Mechanical properties of structures produced by 3D printing from composite materials. MATEC Web Conf., 2019, Vol. 254, 01018. DOI: 10.1051/matecconf/201925401018.

[Boloz 2020] Boloz, L. Interpretation of the results of mechanical rock properties testing with respect to mining methods. Acta Montanistica Slovaca, 2020, Vol. 25, No. 1, pp. 81-93.

[Dodok 2017] Dodok, T., et al. Workshop programming as a part of technological preparation of production. Advances in Science and Technology - Research J., 2017, Vol. 11, Issue 1, pp. 111-116. DOI: 10.12913/22998624/66504.

[Dzhus 2020] Dzhus A., et al. Evaluation the stress-strain state of pumping equipment in the curvilinear sections of the wells. Management Systems in Production Engineering, 2020, Vol. 28, pp. 189-195.

[Flegner 2015] Flegner P., et al. Application of adaptive filters in rock separation by rotary drilling process identification. Acta Montanistica Slovaca, 2015, Vol. 20, No. 1, pp. 38-48.

[Han 2017] Han, C., et al. Analysis of abrasion for stator bushings of equal thickness screw pump in high temperature and sand crude oil. Zhongguo Jixie Gongcheng/China Mechanical Engineering, 2017, Vol 28, Issue 4, pp. 446-450.

[Hortobagyi 2021] Hortobagyi, A., et al. Holographic Interferometry for Measuring the Effect of Thermal Modification on Wood Thermal Properties. Applied Sciences, 2021, Vol. 11, No. 6. DOI: 10.3390/app11062516.

[Hu 2022] Hu, J., et al. Autonomous dynamic line-scan continuous-wave terahertz non-destructive inspection system combined with unsupervised exposure fusion. NDT & E International, 2022, Vol. 132, 102705. https://doi.org/10.1016/j.ndteint.2022.102705.

[Ivanova 2020] Ivanova, T.N., et al. Analysis of distortion mechanisms used in rotary steerable systems. Multidisciplinary Aspects of Production Engineering, 2020, Vol. 3, Issue 1, pp. 331-346.

[Jami 2019] Jami, M., et al. GIS-based Analysis of Relative Tectonic Activity in Southeast of Iran with a focus on Taftan volcano. Acta Montanistica Slovaca, 2019, Vol 24, No. 4, pp. 351-365.

[Kalentev 2017] Kalentev, E., et al. Numerical analysis of the stress-strain state of a rope strand with linear

contact under tension and torsion loading conditions. Advances in Science and Technology Research Journal, 2017, Vol. 11, Issue 2, pp. 231-239. DOI: 10.12913/22998624/71181.
[Kleczek 2016] KLeczek, S.I. The study of the elastic properties of carbonate rocks on a base of laboratory and field measurement. Acta Montanistica Slovaca, 2016, Vol. 21, No. 1, pp. 76-83.
[Kuznetsov 2020] Kuznetsov, E., Nahornyi, V., Krenicky, T. Gas Flow Simulation in The Working Gap of Impulse Gas-barrier Face Seal. Management Systems in Production Engineering, 2020, Vol. 28, No. 4, pp. 298-303.
[Lao 2016] Lao, L.M., et al. Application and effect of buoyancy on sucker rod string dynamics. Journal of Petroleum Science and Engineering, 2016, Vol. 146, pp. 264-271.
[Li 2014] Li, Z., et al. Survey of measurement-while-drilling technology for small-diameter drilling machines. Electronic Journal of Geotechnical Engineering, 2014, Vol. 19, pp.10267-10282.
[Li 2015] Li, Q., et al. How extremely High-TDS produced water compositions affect selection of fracturing fluid additives. In: SPE International Symposium on Oilfield Chemistry. The Woodlands, 2015, 173746. DOI: 10.2118/173746-MS.
[Li 2019] Li, Q., et al. Study on Equivalent Viscous Damping Coefficient of Sucker Rod Based on the Principle of Equal Friction Loss. Mathematical Problems in Engineering, 2019, 9272751.
[Liang 2016] Liang, T. et al. Identifying and evaluating surfactant additives to reduce water blocks after hydraulic fracturing for low permeability reservoirs. In: SPE Improved for Oil Recovery Conference, Tulsa, OK, 2016, 179601. DOI: 10.2118/179601-MS.
[Moroz 2020] Moroz, L., et al. Effectiveness research of physical and chemical methods application for oil recovery enhancing using the asp for the strutynsky oil field conditions. Management Systems in Production Engineering, 2020, Vol. 28, Issue 2, pp. 104-111.
[Pivarciova 2019] Pivarciova, E., et al. Design of the construction and research of vibrations and heat transfer of mine workings. Acta Montanistica Slovaca, 2019, Vol. 24, Issue 1, pp. 15-24.
[Qazizada 2016] Qazizada, M.E., et al. Analysis performance characteristics of centrifugal pump. MM Science Journal, 2016, Vol. October, pp. 1151-1159.
[Qazizada 2018] Qazizada, M., Pivarciova, E. Reliability of parallel and serial centrifugal pumps for dewatering in mining process. Acta Montanistica Slovaca, 2018, Vol 23, pp. 141-152.
[Raimbay 2017] Raimbay, A., et al. Effect of Fracture Roughness, Shear Displacement, Fluid Type, and Proppant on the Conductivity of a Single Fracture: A Visual and Quantitative Analysis. SPE Res Eval & Eng, 2017, Vol. 20, pp. 446-470. DOI: https://doi.org/10.2118/171577-PA.
[Rybar 2017] Rybar, P., et al. Computer modelling as a basic research and visualisation tool to research defunct historical mining technologies, using the example of cementation water mining in Smolnik (Slovakia). Acta Montanistica Slovaca, 2017, Vol. 22, No. 3, pp. 313-322.
[Saga 2019] Saga, M., et al. Contribution to random vibration numerical simulation and optimisation of nonlinear mechanical systems. Scientific J. of Silesian University of Technology-series Transport, Vol. 103, pp. 143-154. DOI: 10.20858/sjsutst.2019.103.11.
[Savenok 2020] Savenok O. V., et al. Application of superdeep drilling technology for study of the earth crust. IOP Conference Series: Earth and Environmental Science, 2020, pp. 052-066.
[Strzalkowski 2019] Strzalkowski, P., et al. The influence of extraction speed on the value of the coefficient of subsidence rate. Acta Montanistica Slovaca, 2019, Vol. 24, No. 4, pp. 331-341.
[Velychkovych 2020] Velychkovych, A., et al. Analytical Study of Operational Properties of a Plate Shock Absorber of a Sucker-Rod String. Shock and Vibration, 2020, 3292713.
[Wang 2016] Wang, X., et al. Surface subsidence control during bag filling mining of super high-water content material in the Handan mining area. Int. J. Oil Gas Coal Technol., 2016, Vol. 13, pp. 87-102.
[Wang 2017] Wang, D.Y., Liu, H.Z. Dynamic modeling and analysis of sucker rod pumping system in a directional well, Lecture Notes in Electrical Engineering, 2017, Vol. 408, pp. 1115-1127.
[Xing 2014] Xing, M., Dong, S. An improved longitudinal vibration model and dynamic characteristic of sucker rod string. Journal of Vibroengineering, 2014, Vol. 16, No. 7, pp. 3432-3448.

CONTACTS:

Tanyana N. Ivanova
Tchaikovsky Branch "Perm National Research Polytechnic Institute"
617764, Lenin st. 73, Tchaikovsky, Udmurtia
tatnic2013@yandex.ru

Aleksandr I. Korshunov
Federal State Budgetary Institution of Science "Udmurt Federal Research Center of the Ural Branch of the RAS"
Institute of Mechanics, 426000, T. Baramzinoy str., 34, Izhevsk, Udmurtia
maguser_kai@mail.ru

Veronika Kvorkova, Ing. PhD.
Maros Soldan, prof. Ing. PhD.
Slovak University of Technology in Bratislava
Faculty of Materials Science and Technology in Trnava
Institute of Integrated Safety
Jana Bottu 2781/25, 917 24 Trnava, Slovakia
veronika.kvorkova@stuba.sk; maros.soldan@stuba.sk