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ANALYSIS AND JUSTIFICATION OF SELECTION OF FLUIDS TO BE USED FOR WATER SHUT-OFF TREATMENT DURING WELL COMPLETION

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АНАЛИЗ И ОБОСНОВАНИЕ ВЫБОРА СОСТАВОВ ДЛЯ ОГРАНИЧЕНИЯ ВОДОПРИТОКОВ ПРИ ЗАКАНЧИВАНИИ СКВАЖИН

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well drilling, challenges, water inflow, production formation, isolation, formation blockage, gas-liquid mixtures, foams, viscoelastic mixtures, abnormally low reservoir pressures, well completion, laboratory study, penetration, rheology, density.

The aim of the work is to increase efficiency of well completion under conditions of water inflow by use of viscoelastic gas-liquid mixtures to shut-off permeable formations.

At present, there is an increase in rates of drilling of wells in abnormal conditions, such as abnormal formation pressure (both low and high), unstable rocks, rocks of high hardness, permafrost etc. The quality of well construction in such conditions influences subsequent development and operation of the field greatly. Aquifer isolation is an extremely important issue due to the fact that from them water breaks through in production wells which has a significant impact on quality of fluid produced.

The main solution for water breakthrough challenge is formation isolation, which is performed by use of various plugging material. At present, there are many mixtures that limit water inflows such as fast-setting plugging materials, gel-cement mixtures, polymeric swelling nets, latexes, synthetic resins, viscoelastic mixtures, materials for selective isolation etc.

Under conditions of abnormally low reservoir pressures, it is important to consider density when selecting drilling fluids and plugging materials. Therefore, it is recommended to use screens based on viscoelastic three-phase stabilized gas-liquid mixtures for temporary blockage of permeable aquifer. With use of such mixtures liquid penetration flow rate is significantly reduced compared to other viscoelastic systems, which makes it possible to increase reliability of temporary isolation of aquifers.

The paper presents an analysis of domestic and foreign experience of blocking permeable formations by different mixtures. Three-phase blocking mixtures are studied and requirements for them are generalized.

Ключевые слова:

бурение скважин, осложнения, водопритоки, продуктивный пласт, изоляция, блокирование пласта, газожидкостные смеси, пены, вязкоупругие составы, пониженные пластовые давления, заканчивание скважин, лабораторные исследования, фильтрация, реология, плотность.

Целью работы является повышение эффективности заканчивания скважин в условиях водопритоков благодаря применению вязкоупругих газожидкостных смесей (ГЖС) для изоляции проницаемых горизонтов.

В настоящее время происходит увеличение темпов бурения скважин в осложненных условиях, таких как аномальные пластовые давления (как низкие, так и высокие), неустойчивые породы, породы высокой твердости, многолетнемерзлые породы и др. Качество строительства скважин в таких условиях во многом оказывает влияние на последующую разработку и эксплуатацию месторождения. Особенно остро стоит вопрос изоляции водоносных пластов, из которых происходят прорывы вод в добывающие скважины, оказывающие существенное влияние на качество добываемой продукции.

Основным решением проблемы прорыва вод является изоляция пластов, которая осуществляется применением различных тампонажных материалов. В настоящее время существует множество составов для ограничения водопритоков: быстросхватывающиеся тампонажные материалы, гелцементные растворы, полимерные набухающие сетки, латексы, синтетические смолы, вязкоупругие составы, материалы для селективной изоляции и др.

В условиях пониженных пластовых давлений при выборе буровых технологических жидкостей и тампонажных материалов важно учитывать плотность, поэтому для временного блокирования проницаемого водоносного горизонта целесообразным является применение экранов на основе вязкоупругих трехфазных стабилизированных ГЖС. При использовании таких составов значительно понижается скорость фильтрации жидкости по сравнению с другими вязкоупругими системами, что позволяет повысить надежность временной изоляции водоносных горизонтов.

В работе проведен анализ отечественного и зарубежного опыта блокирования проницаемых пластов различными составами, исследованы трехфазные блокирующие составы и обобщены требования к ним.

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Introduction

An analysis of current state of development of oil and gas fields shows that significant amount of production wells is operated with more than 80 % of water cut. Inactive wells represent more than 35 % and for some fields it is about 40-50 % of total amount. At the same time, there are at least 15 % of wells that have water cut sharply after they are put on production [1-4].

Breakthrough of water into production wells is often caused by presence of cross-flow due to poor quality of cement that can be caused by [5]:

- wrong density of cement slurry, when pressure in oil-bearing formation is higher than pressure created by slurry column;
- poor quality adhesion at interfaces ("rock-cement" and "cement-casing"), caused by poor quality removal of filter cake (especially during well flush by hydrocarbon-based solutions) and volume shrinkage of cement stone;
- premature thickening that cause decrease in hydrostatic pressure and, as a result, migration of fluid from the formation;
- low quality of cement slurry due to excessive water loss, low sedimentation resistance, high permeability, low strength and shrinkage of forming cement stone.

Today, there are several ways to overcome the challenge of qualitative isolation of water-bearing formations that are selective isolation of water inflows during repair and isolation works [6, 7], improvement of quality of well cementing [8-18] and temporary blockage of the reservoir [19-21].

In order to prevent channels to form by the migration of fluid from a well during thickening of cement the most expedient is to block permeable water-bearing formation for some time.

Current state of the challenge

Analysis of scientific and technical papers in the field of isolation of water inflows during oil production, as well as isolation of water-bearing formations during drilling and operation [3] shows trend of decrease in use of cement slurries during repair and isolation work. It is also found that a share of complex technologies and methods of selective isolation is increasing. Nevertheless, there is almost no attention paid to cross-flow prevention.

During construction of wells under conditions of low (including abnormally low) pressures, well pressure plays a significant role. Therefore to block permeable intervals it is advisable to use low density mixtures such as three-phase foams. It was concluded in [22] that character of fluid flow in porous medium saturated with a three-phase foam nature of the solid phase has significant influence. According to that clays are recommended for isolation of non-oil-bearing formation and acid-soluble colmatants for oil-bearing ones. Parameters of mixtures that have been used for isolation of bottomhole formation zone are given in Tables 1 and 2.

In some cases in order to block a formation hydrocarbon-based mixtures that include crumb rubber are used. It leads to inconvertible blockage of a formation and permeability decrease because of crumb that do not dissolve and biodegrade during acid treatment. Thus, the mixture can be applied only in non-oil-bearing permeable formations to control loss circulation of flush fluid but only for drilling wells with flushing by hydrocarbon-based fluids.

If instead of crumb rubber calcium carbonate is used as filler material then mixtures can be used for temporary blockage of oil-bearing formation. Herewith such mixtures can be easily removed during acid treatment after perforation.

Foam mixtures (Table 2), designed to shut-in wells in abnormally low reservoir pressures, can be successfully applied to temporarily blockage of bottomhole zone and restriction of water inflows into the well.

Stable three-phase foams, which serve as a flow screen, are the most efficient. Due to the solid phase that is added to foam, stability of a foam increase, structural and mechanical properties improve and penetration intensity decreases. Presence of bentonite as a solid phase can lead to inconvertible colmatation of a permeable formation.

On the one hand, presence of chalk as filler and a solid phase to block temporary formation pores increase blockage abilities, on the other hand, complicate put-on production because a formation has to be unblocked. In order to unblock oil-bearing formation from chalk during acid treatment its natural permeability is deformed due to interaction between the acid, minerals and formation water.

Table 1

Mixtures that block formation bottom hole zone

Patent of RF	Composition	Parameters	Features
No. 484300 [23]	A mixture of condensate and sulfite-alcohol spent wash (SASW) in a ratio of 3:1. The water solution of SASW is 38 % (25-50). Rubber crumb (0.2-0.5%).	Density – 0.9–0.95 g/cm ³ . SSS – 80 Pa·s	High static shear stress
No. 2255209 [24]	Hydrocarbon base (41-72). Acyclic acid (6-14). Caustic soda (4-13). Mineral filler	Emulsion density – 1.02 g/cm ³	Insufficiently high efficiency of application in the fields with high permeability formation
No. 2196164 [25]	Gas condensate (5-75 %). SASW, concentration 38 % (25-50 %). Rubber crumb (0.25-0.5 %)	Density – 1030 kg/m ³ , viscosity – 42 s, SSS _{1/10} – 2/3 dPa, DSS – 37.5 dPa, Plastic viscosity – 129.5 mPa·s	Inconvertible blockage of pore space of oil-bearing formation
No. 2309177 [26]	CMC (1.5-2.0 %). Magnesium chloride (12-18 %). Sodium hydroxide (10-16 %), Water – the rest. In addition over 100 %: microspheres (25-40 %); chalk (3-5 %)	Density – 1300 kg/m ³ , viscosity – 60 s, penetration – 6 cm ³ , stability – 10 min	Ensuring blockage of bottomhole formation zone of high permeability ("super reservoirs") and cracks

Table 2

Foam mixtures designed to block a formation and limit water inflows

Patent of RF	Composition	Features
No. 1175951 [27]	Lignin (8.0-15.0). Alkali (0.3-5.0). CMC (0.2-0.6). Surfactant (0.01-0.15). Petroleum product (1.0-5.0). Ethylenediamine (0.05-1.5). Water – the rest	Instability of a system, weak ability to block, negligible decrease in permeability of reservoirs after workover
No. 1208192 [28]	Sulfonol or OP-10 (1-3). Bentonite (1-3). PAA (0.5-0.7). CSASW-4 (5-8). Fresh water – the rest	Instability of a system, weak ability to block, decrease in permeability of reservoirs after workover, significant time expenditures to put a well on production
No. 2183735 [29]	Surfactant (0.5). Potassium chloride (5.0). Hydroxyethyl carboxymethyl starch (3.0-4.0). Condensed SASW (0.5-1.0). Chalk (3.0). Water – the rest	Insufficient well killing. Formation of foam with low multiplicity
No. 2187533 [30]	Foaming agent (0.8-1.8). Modified starch (5.0-7.0). Sulfacell (0.18-0.3). Chalk technical (3.0-4.0). Alumino chloride (1.1-1.4). Calcined soda (0.6-0.8). Fresh water – the rest	Insufficient well killing

The main requirements for blocking mixtures are high viscosity, wide limits of regulation of structural, mechanical and rheological properties, low penetration value, preservation of reservoir properties and operating reservoir parameters (with a probability of penetration into oil-bearing formation), available components, a simple technology of preparation in field conditions, ensuring work safety.

To block high permeability zones it is necessary to use a colmatant whose dimensions depend on formation pore size. The most suitable for this purpose is calcium carbonate of coarse fraction or microspheres (glass, aluminosilicate or ceramic).

General requirements for mixtures for temporary formation isolation under conditions of low pressures are as follows:

1. A blocking mixture should be chemically inert to rocks, compatible with formation fluids and should avoid inconvertible reservoir pore blockage by solid particles.

2. The filtrate of blocking mixture must have an inhibitory effect on clay particles, preventing their swelling at any pH value of formation water.

3. The mixture should have thixotropic properties, in particular little resistance when moving in drill pipes and annulus and large when moving in permeable rocks.

4. Blocking mixture liquid must have low corrosive effect on downhole equipment. The rate of corrosion of steel should not exceed 0.10-0.12 mm/g.

5. Blocking mixture for isolation should be thermostable at high temperatures and frost-resistant in winter conditions.

6. Blocking liquid must not be combustible, explosive and non-toxic.

7. Blocking mixture must be technological in preparation and use.

8. Technological properties of liquid for blocking must be regulated.

9. In fields with presence of hydrogen sulphide, mixtures must have a neutralizer of hydrogen sulphide.

Thus, development of a composition for temporary isolation of permeable water-bearing formation, which minimizes fluid penetration in a system "well-reservoir" and contamination of bottomhole formation zone, as well as a method of its removal from oil-bearing formation after jobs for subsequent shut-in and production, is an extremely important goal. An obtained result needs comprehensive study.

Development of gas-liquid blocking liquid

In order to put well on production effectively in conditions of low pressures and preserve reservoir properties to ensure temporary isolation it is needed to use gas-liquid blocking liquid with following parameters:

- density – less than 1000 kg/m³;
- fluid penetration – no more than 5 cm³/30 min;
- mud cake thickness – 0.5-1.0 mm;
- hydrogen index (pH) – 7-8;
- efficient viscosity – at least 65 mPa·s;
- dynamic shear stress (at surface/bottomhole) – 400-1000/150-700 dPa;
- static shear stress (1 min/10 min) – at least 15/15 dPa.

An oil-bearing formation can be characterized by high temperatures up to 90-100 °C. So, it is recommended to use heat-resistant gas-liquid blocking liquids that retain their properties during the entire time of liquid being in a well.

Thus, development of thermostable blocking liquids that have mentioned properties is a high priority issue.

A solution should include components that are as follows:

- polymer (biopolymer) to form a structure of gas-liquid blocking mixture;
- regulator of pH;
- bactericide (in case starch reagents and biopolymers used);
- viscosity regulator;
- flow properties regulator;
- colmatant (to increase stability);
- additional components.

At the first stage, drilling muds are selected for density and fluid penetration matching. Studied solutions are given in Table 3.

Table 3

Composition of studied solutions, %

Reagent	Solution							
	1	2	3	4	5	6	7	8
Biopolymer	2.6	1.5	1.5	0.5	0.3	0.3	0.4	0.3
Surfactants	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.08
Colmatant	2.0	2.0	2.0	1.0	1.0	1.0	0.8	0.8
pH regulator	0.06	0.06	0.06	0.06	0.0	0.06	0.06	0.06

In addition, stability was measured and multiplicity of the foam obtained was calculated. Results of experimental studies are presented in Table 4.

Table 4

Results of experimental studies

Parameter	Solution							
	1	2	3	4	5	6	7	8
Density, kg/m ³	920	840	780	800	820	800	810	800
Conditional viscosity, s	Non-flowing				45	55	150	99
Multiplicity of foam	1.44	1.5	1.68	1.64	1.6	1.64	1.5	1.7
Dynamic viscosity, cP:								
3 rpm					1300	1367	1500	1100
6 rpm					783	800	850	650
100 rpm					114	112	96	83
200 rpm					70	68	59	51
300 rpm					50	50	46	37
600 rpm					31	31	26	24
pH	7.8	7.8	7.6	7.5	7.3	7.8	7.6	7.5
Stability, kg/m ³	0	0	0	0	150	200	0	170
Penetration, cm ³ /30 min	0	0	0	0			8.8	

The first four solutions showed high stability (there was no liquid escape from foam during 7 days) high values of resistance, good indexes of stability and fluid penetration, but they do not flow. Therefore, determination of their rheology was impossible. So, they were considered as inexpedient. Dynamic viscosities at different shear rates were measured for compositions 5-8. In general, dynamic viscosities are close to each other for all the solutions, but only 7th solution has acceptable stability (no more than 20 kg/m³). Compositions 5, 6 and 8 delaminated and showed insufficient stability values. There was a negative result for fluid penetration in 7th sample. Therefore, in future research it is recommended to look over solutions that include following components: 0.4-0.5 % of biopolymer, 0.05-0.1 % of a surfactant and 0,8-1.0 % of a colmatant. For control over rheology and penetration properties it is proposed to consider addition of low and high viscosity polyanionic cellulose in various concentrations to obtain optimal values.

Besides, it is necessary to evaluate thermal stability of compositions in the future and investigate technological and rheological properties after heating up to reservoir temperatures (for example, 90 °C), and determine dependence of destruction of three-phase solution with increase in pressure up to reservoir.

Findings and recommendations

1. Temporary isolation is a necessary technical operation that is complicated by low reservoir pressure. Application of the products with low density, such as emulsions and foams, is important.

2. In case of temporary isolation, it is necessary to consider a possibility of penetration of blocking liquid into bottomhole zone of oil-bearing formation. As a result, it is necessary to exclude insoluble in acids colmatant from composition of developing solutions.

3. Foams used to create a blocking screen must be stable from the moment of pumping until the end of cement thickening. Ground calcium carbonate is an effective filler to stabilize a solution. Calcium carbonate is dissolved easily during acid treatment.

4. The most successful blocking mixtures are liquids with a low dynamic shear stress at surface conditions and with a high pressure in bottomhole formation zone. That allows reducing the probability of penetration of liquid into an oil-bearing formation and decreasing reservoir properties. High values of dynamic shear stress at surface conditions reduce performance factor and efficiency of a pump. Thus, forthcoming rheological studies should be focused on test of stated requirements and development of new solutions in case of negative result.

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