WATER PRODUCTION ISOLATION TECHNIQUES FOR OIL-WELLS WITH HIGH RESERVOIR TEMPERATURE

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Advanced drilling technology makes it possible to penetrate oil and gas sites with deep bedding of oil reservoir, a complex multi-layer structure and a high reservoir temperature at the well bottom, reaching 150°C. The difficult geology of oil strata leads to the fact that the productive layers of a well are flooded unevenly. In this work the causes for water cut in reservoirs are given, repair and insulation work and technologies for isolation of water-bearing intervals in the oil-producing wells considered. Grouting composites for water inflow limitation in reservoirs with low temperature (up to 100°C) and high-temperature reservoirs are studied. For water flood control in the oil and gas wells with high temperature viscoelastic composites with extended gel-time and high stable strength and adhesive properties has been proposed. The advantage of polymer-based composites is their kinetic behavior in dynamic mode, when filtering in a porous medium, which makes it possible to isolate effectively intake formations with different channel openings with a small flow rate of the mixture.

KEYWORDS

Polymer, encroachment, reservoirs, adsorption

1 INTRODUCTION

Advanced drilling technologies enable oil and gas sites with deep bedding of oil reservoir, a complex multi-layer structure and a high reservoir temperature at the well bottom, reaching 150°C to be penetrated [Kuznetsov 2020]. These are the deposits of Western Siberia, the Komi Republic, Kazakhstan, and Vietnam.

Taking into account the rapid increase in water cut in production and the low recovery efficiency during the operation of oil and gas fields, there are repair and insulation works aimed at isolating the water flow into the well (Fig. 1).

The schemes of water shut off technologies in oil wells with high reservoir temperatures are as following:

- Selective ones which mean control of the working parts of the formation in the perforation range;
- Cutting-off schemes imply cutting off the part of the effective thickness within perforation interval;
- Cutting-off with reperforation schemes are based on cutting off a part of the effective thickness within perforation interval with reperforation of new productive reservoirs;
- Well re-completion approaches mean complete isolation of the previous perforation interval and integration of another pay thickness.

All these schemes use structure-forming composites based on artificial resins, water-soluble polymers, and silicate-based inorganic compounds (Fig. 2).

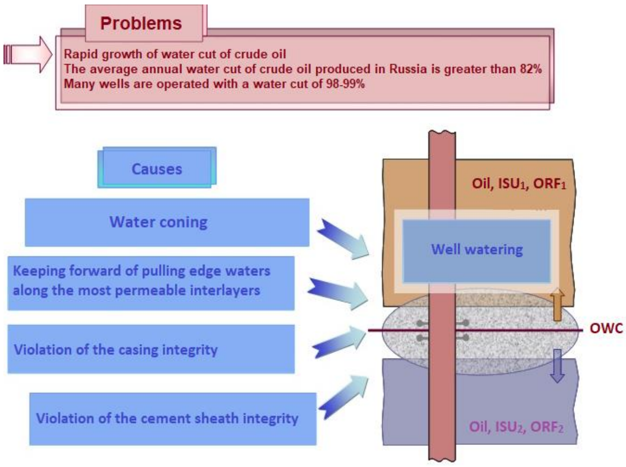

Figure 1. Repair and insulation work: ISU1, ISU2, are indices of stratigraphic units; ORF1, ORF2 – oil recovery factors, OWC – oil-water contact

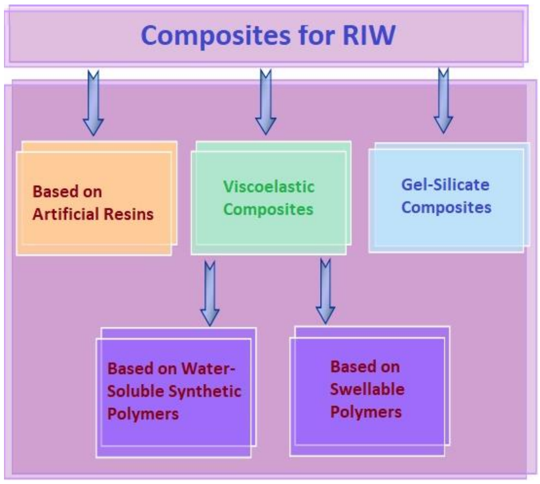

Figure 2. Composites for technologies of repair and isolation works (RIW)

The complex structure of the formations leads to uneven water flooding the pay zones of a well [Antuseva 2013, Ovchinnikov 2014, Manzhay 2017, Thomas 2017]. If the productive part of the reservoir is not stopped-up, then the balance is disturbed, and it is impossible to achieve natural insulation of the reservoir. If water, exuding from injection wells or active aquifers, displacing oil from the formations, enters the well in a volume less than the limit corresponding to the critical water-oil factor, then the produced water is classified as the first type. The second type includes water that enters the well and is produced either with oil or with no oil in an amount insufficient to cover the costs associated with its disposal, i.e., the volume of water exceeds the economic limit determined by the water-oil rate (WOR). The causes for the appearance of water of the second type in the well are in Table 1 [Kiseleva 2016, Avanesova 2018, Elbakian 2019, Minaev 2021]. Regardless of the type of grouting compounds, there are uniform technical requirements (Fig. 3) [Belyaev 2020, Kurochkin 2014, Saga 2019, Beliajeva 2019].

For reservoirs with low temperatures (up to 100°C), initial composites are low or moderately viscous aqueous solutions, which upon the chemical reactions, yields a hydrogel with filtration, strength and adhesion characteristics regulated in a wide range. The formation time for the structure and its stability are largely determined by the formation temperature.

Table 1. Problems of Excess Water Inflows

Problems	Causes	Solutions to the Problems	
		Vertical Wells	Horizontal Wells
Casing leak, leak of tubing or packer	Deterioration of well stock; Process reasons; Corrosion attack	Application of the insulating fluids, plugs, cement bridges, packers; Application of patches	
Behind-the-casing water flow	Low quality of cement stone; Voids in the behind-the-casing space	Application of insulating fluids (pumping of high-strength cement or resinous polymers into the annulus or injection less durable gel-based fluids into the formation to stop the flow into the annuluse)	
Promotion of the oil-water contact (OWC)	- Low vertical permeability	Plugging of the lower perforation holes with mechanical systems	Sidetracking of the horizontal hole
Water-yielding interval in productive zone with no formational cross flow	Highly permeable intervals, limited at the top and bottom by water-tight barriers	Use of inelastic insulating fluids or mechanical isolator	Horizontal wells which unseal one core interval do not have this kind of problems
Fracturing or cross-boreholes fractures between injectors and producers	-Presence of fractured or fractured-porous formations	Injection of gels; Water insulation	
Fissures or fractures that connect oil and water reservoirs	Presence of a fissure system intersecting the water reservoir	Treatment of fissures with gel composites; Blockage of fissures in a well-bore zone	
Conning and cusping	Oil-water contact at the same level as perforation hole; High vertical permeability	Injection of large volumes of gel layer above the lower perforation holes, Drilling of horizontal shafts near the top	Insulation in the borehole zone for sufficient distances along the wellbore down and up
Low horizontal sweep efficiency	Heterogeneity of permeability over the area; Proximity to the water spring	Deviation of the flow of injected water; Infill drilling	Isolation of the parts of the well
Formation stratified in terms of saturation by gravity separation of fluids	Gravity separation of fluid	Sidetracking of the horizontal hole; Waterflooding with foams	Sidetracking of the second hole, closer to the top of the formation
Water-yielding interval in productive zone with inter-formational cross flow	Highly permeable interlayers, not separated by impermeable bridges	Deep injection of gel intoa thin watered formation; Lateral drilling	Horizontal wells located in the same interlayer do not have this kind of problems

Table 2. Grouting composites for water inflow limitation in reservoirs with low temperature (up to 100° C)

Technology	Features of the technology	Geography of use	Scope of application	Advantages	Disadvantages
Cement	Including the packer in the layout of cementing strings	Cantarelle (Mexico): T = 93°C; k = 1-10 mD; m= 8-35%; h = 30 m	Bottomhole formation zone isolation and additional fastening of gels and other grouting means	Low cost, easy to use	Low efficiency
Polyacrylamide (PAA) with an inorganic crosslinking agent (chromium acetate, sodium dichromate, aluminum citrate, etc.)	High-molecular PAA (MM = 7-25 million, Degree of Hydrolysis = 12-25%) with a concentration of 2-15 kg/m^3, crosslinking agent-chromium acetate or sodium dichromate, injection volume 240-1800 m^3 per well, in some cases overflash to the reservoir deep 3 m	Spring Creek (Canada), Raman (Turkey): hydrodynamic coupling of oil-and water-saturated formations through a system of cracks; Formation pressure = 75-102 atm, m=10-20% Arbuckle (USA) Lamadian (China): T = 45°C; k = 0.2-0.57 micron^2; m=28-31%	Deep crack space insulation	Low cost, good stability in the crack space, control the properties of the gel within a wide range	The possibility of falling into productive intervals
Gels with additional reinforcement with cement	20-21% concentration; Volume of injection - 4.9-10.2 m^3	Pembina (Canada)	Isolation	Typical for gel	Strict compliance with the recipes; Low quality of cementing makes removal possible
Polymer-dispersed composite	Organically cross-linked polymer and fine silica: Viscosity factor – 20-30 cP; Temperature stability – 27-177°C; withstands pressure overbalance 17.2 MPa	Mexico, Russia	Deep crack space insulation	High strength of the gel composite; Stability to shear deformations	Complexity of destruction in case of reservoir contamination
Foam-gel composites	High-molecular-weight PAA: MM=11.6 million; Degree of Hydrolysis = 24%; Cross-linking system = sodium dichromate + sodium sulfite	Hushaoshan (China)	Deep crack space isolation	Improved insulation properties compared to gels	Special compression equipment

The global experience of using grouting compounds for water-bearing intervals in carbonate-fractured reservoirs to be isolated is summarized in Table 2.

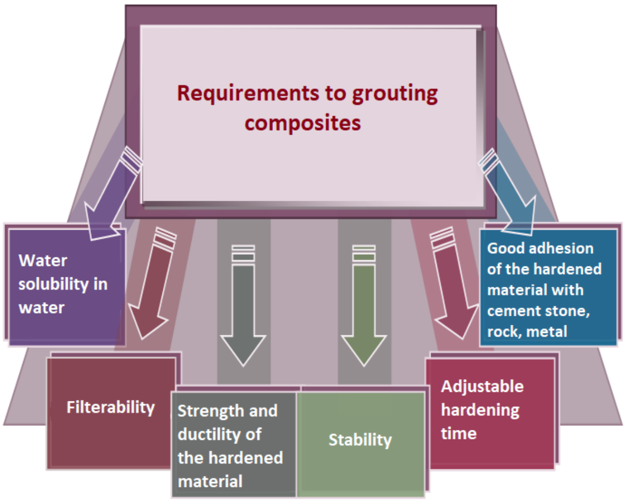

Figure 3. Requirements for grouting composites

2 METHODS AND MATERIALS

For high-quality and long-term protection of the productive intervals against water inflows, it is preferable to use grouting compounds that make possible to develop an extended screen. These properties are inherent in non-crosslinked gel systems.

Existing composites of polysaccharide gel containing fresh or mineralized water, polysaccharide thickener, boric cross-linking agent, diethanolamine and quaternary ammonium compounds (Patent RU 2173772, MPK E21B 43/26, published 20.09.2001; Patent RU 2346151, MPK E21B 43/22, C09K 8/514, published 10.02.2009, Journal for Patents, No. 4; Patent RU 2246609, MPK E21B 43/12 published 20.02.2005, Journal for Patents, No. 5) are failure at high-temperature wells. That occurs either because of the high adsorption of cationic surfactants on the rock and reducing the flow of oil stemming from increasing of interfacial tensions at the surface with oil, or because of the long gelation time. Another cause is the multicomponent composition, which has low robustness to the preparation of the composite in a field situation. Also, many gel formulations are not effective due to the fact that they contain nonionic surfactants that are not stable under the influence of high temperatures.

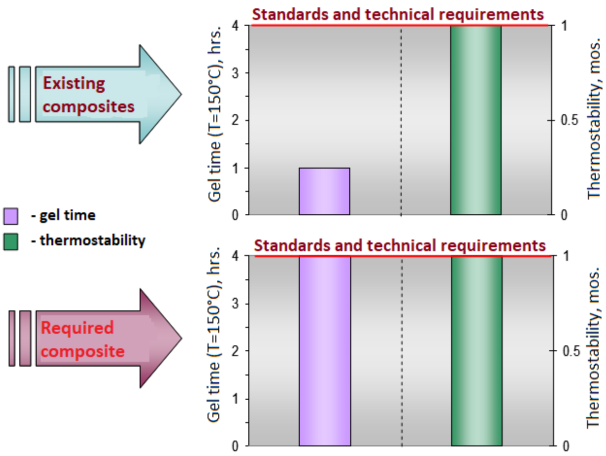

Figure 4. Development of thermostable composites

For high-temperature formations (150°C), the choice of effective gel composites is significantly complicated due to more stringent technical requirements for the composites: the gel formation time should be more than 4 hours, the residual resistance factor is greater than 100, the initial shear pressure gradient of the formed gel is higher than 2.5 atm/m, and the gel thermal stability is more than 1 month. These requirements are met by inorganic gels that retain their original filtration and strength characteristics for six months at temperatures of at least 160°C. However, gel-forming composites of inorganic origin are fragile, do not have elastic properties and the ability to undergo reversible deformation, which is indispensable to water flow isolation in fractured reservoirs [Pivarciova 2019, Kuric 2019, Wiecek 2019]. If a composite based on organic gels in particular, based on acrylamide polymers, is considered, then it has all these properties. The results of comparison over the temperature range are shown in Fig. 4.

The analysis of existing at present stage approaches towards the development of compositions allows conditionally highlighting two following directions of current consideration:

1) modification of structure-forming compositions based on low-molecular polyacrylamide AK-642 with various additives to extend the gelation period under an elevated temperature;

2) synthesis of new water-soluble polymers, selection of cross-linkers and creation of compositions based on them with high thermal stability and a long period of gelation.

3 RESULTS

The use of modifying additives (organic weak acids) makes it possible to extend the gelation period of composites based on AK-642-chromium acetate from 2-5 minutes to 4-5 hours at 90°C. At a temperature of 120°C, the gelation time is 10 minutes. This is not enough, especially if the large volumes of water are to be pumped. The second direction appeared is more promising (Fig. 5).

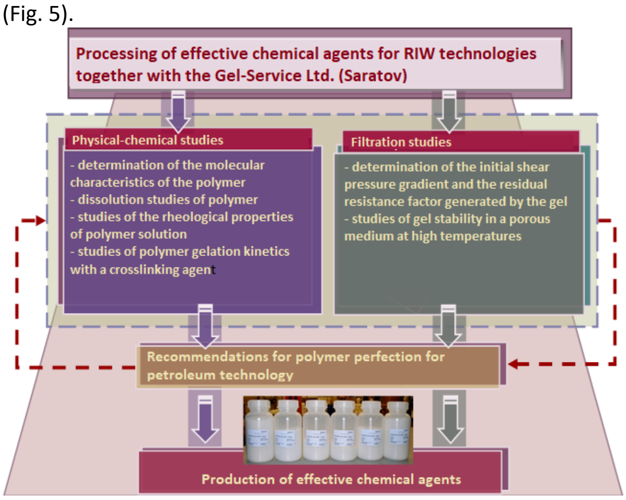

Figure 5. Testing of effective reagents for repair and insulation works (RIW)

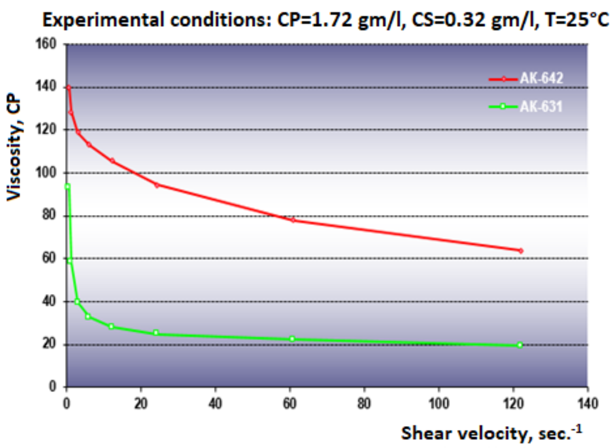

Figure 6. Rheology of polymer solutions AK-631 and AK-642

The resulting polymer AK-631 is not subject to mechanical and thermo-oxidative degradation, low viscosities ensure selectivity of filtration in a porous medium (Fig. 6), and is used in a wide temperature range from 70 to 150°C. At reservoir temperatures up to 100°C, chromium acetate acts for crosslinking agent (without additives); at temperatures over 100 to 150°C a crosslinking agent based on organic heterocyclic compounds is used, which increases the gelation time (Fig. 7).

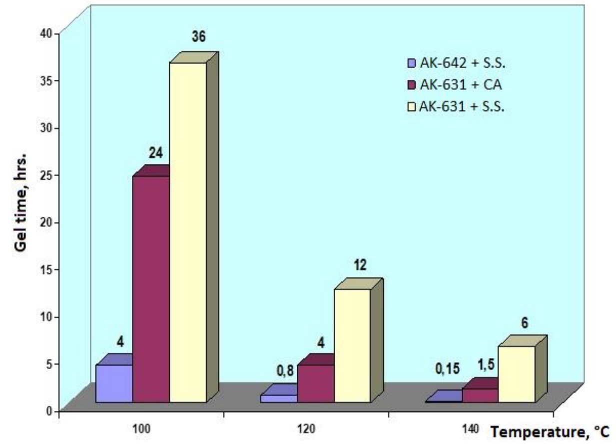

Figure 7. Ranges of gelation time variation as a function of temperature

While filtration in a porous medium is going on, the based on the AK-642 polymer composite is changing dynamically so that polyacrylamide and chromium acetate at high temperatures at the initial stage due to the formation of micro-gel particles, and their accumulation in the narrowing of pores and leading toward slowing rates of filtration (Fig. 8). AK-631 polymer fails to provide slowing rates of filtration.

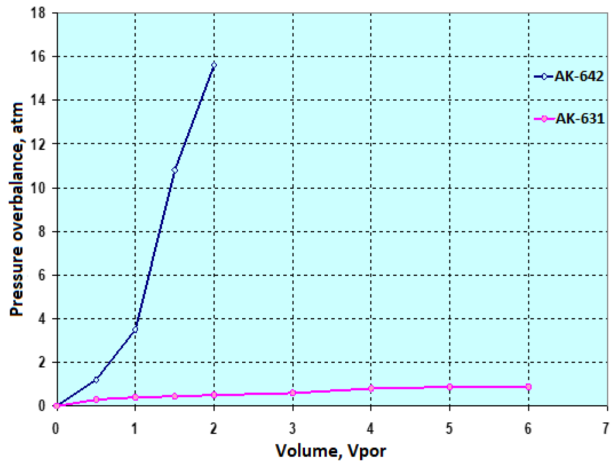

Figure. 8. Dynamics of resistance changes during filtration of gel-forming composites in a porous medium: permeability: 4 µm², flow rate: 1 cm³/min, temperature: 90°C

The change in the viscosity of the AK-631 polymer composites as a function of the composition heating temperature (from 30°C to 150°C) and the formation temperature is shown in Fig. 9.

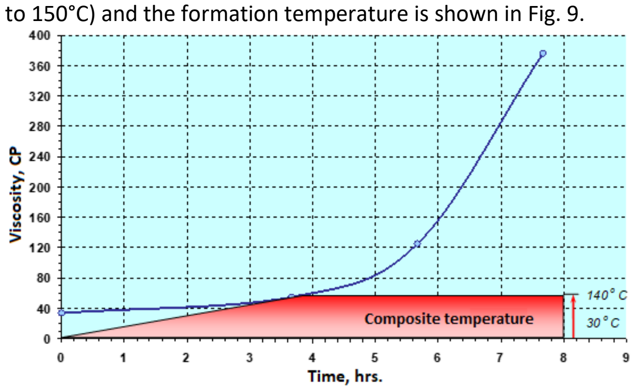

Figure 9. Effect of heating time and temperature on the viscosity of gel-forming composites

The heating rate is 0.5°C per minute. This mode corresponds to a volume injection rate 3 m³ per hour. In the mode of heating to a reservoir temperature of 140°C, a slight increase in the viscosity of the composites is observed. Under isothermal reservoir conditions, the viscosity in-creases more sharply, but there is no complete loss of pour point of the composites.

The strength and adhesive properties of polymer composites in a porous medium, which ensure the strength of gel adhesion during crack space isolation, are shown in Figs. 10 and 11.

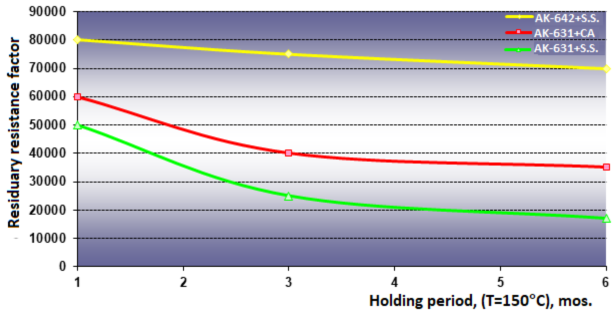

Figure 10. Stability of the composites at a temperature of 150°C

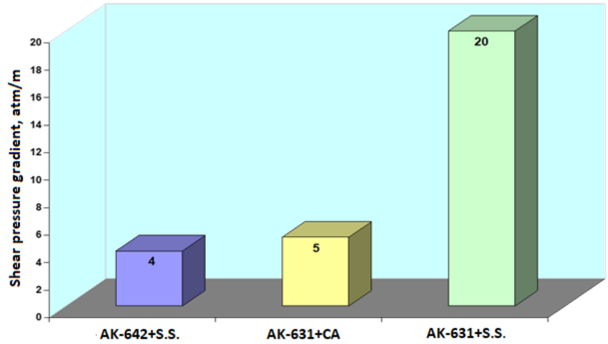

Figure 11. Strength characteristics of polymer composites, chromium acetate, sodium salt

4 CONCLUSIONS

In order to cut off the water flow in oil and gas wells with high formation temperature viscoelastic composite with extended gelation time and high stable strength and adhesive properties has been proposed. Polymer composites AK-642 is proven as highly effective in processing heterogeneous oil and gas reservoirs in production and injection wells with injection into watered and washed highly permeable intervals of various flow-deflecting and water-insulating composites.

The advantage of polymer-based AK-631 composites is their kinetic behavior in dynamic mode, when filtering in a porous medium. The composites based on polyacrylamide and chromium acetate at high temperatures at the initial stage due to the formation of microgel particles accumulates in the narrowing of pores and decreases filtration. In the case of filtration of the composites based on AK-631 polymers the filtration attenuation does not occur, which makes it possible to effectively isolate intake formations with different channel opening rates with low composites consumption.

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