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Intensification of oil production through the use of hydraulic fracturing fluid based on polyacrylamide

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Abstract. The article considers the technology of Hydraulic Fracturing (HF) based on polyacrylamide (Co-PAM), identifies parameters for evaluating the quality of the fluid both on a guar and polyacrylamide base. Fluid viscosity is a main criteria of success of HF operations. Thus, fluid thermal stability, determine the pumping time. The composition of the Co-PAM-based HF fluid differs from the guar-based one, consisting of two main chemical reagents - a gelling agent and a crosslinker(x-linker), in that only a synthetic gelling agent is used. Recommended concentration starts from 4 l/m3. At this concentration the synthetic gel starts to exhibit properties of a sand-carrying fluid, suitable for standard pump rate (4.0-5.0 m3/min) HF. A significant advantage is compliance with the requirements for HF fluids which not only improves the filtration properties of the formation but also considers the economic feasibility of using such a chemical reagent. Co-PAM gel using provides reduction of logistics costs, water heating. Also it allows to exclude hydration unit, reduced crew, decreased wear on pumping units, including reduced consumption of lubricants during the HF operation.

1 Introduction

The technology of hydraulic fracturing, also known as fracking, is used to create highly conductive fractures in order to increase the flow of fluids into a wellbore. This method's effectiveness depends on various factors, including the effective thickness of the formation being affected, the level of fluid contact (oil-water contact), the degree of depletion of formation energy, and the water cut in well production. To avoid the negative impacts of creating channels for water filtration, it is important to carefully monitor the proportion of water in the total flow of fluids entering the wellbore. At the Vingapurovskoye oilfield, fracking was first tested in 1991 on object BV_8, and saw significant success in the 2000s, with a success rate of 92%. This technology helped to increase production by 16 million tons

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between 1995 and 2010, accounting for more than 30% of total production during that period [1].

2 Main part

The success rate of fracking operations is 95.1%. Based on the accumulated experience in conducting hydraulic fracturing, this method is considered effective. Fracking not only enhances fluid inflow, but also allows for the involvement of previously undrained areas of a formation, thereby increasing oil recovery. [2, 3].

The goal of conducting fracking is to increase the oil recovery of the formation by creating a wide fracture and fixing it with proppant, for the transportation of which fracturing fluid is used, obtained by adding chemical reagents [4].

The main goal of the hydraulic fracturing process is to increase oil recovery from the reservoir by creating a network of fractures and keeping them open using a propping agent, which is transported using viscoelastic fluids. For some companies, the minimum viscosity of the propping fluid based on x-linked guar at which proppant transport is possible is 400 sP (mPa·s). If the viscosity is lower, the hydraulic fracture fluid loses its ability to hold the sand and the proppant particles start to settle, blocking the perforation zone, making it impossible to continue injecting the gel-proppant mix into the formation. Due to these complications, the costs associated with equipment downtime and associated personnel are added to the overall costs of the hydraulic fracturing operation.

The Vingapurovskoye field applies the following recipe of guar-based fracturing fluid for the BV_8 formation (Table 1).

Table 1. Recipe of guar-based fracturing fluid

Name	Reagent	Unit	Loading
Gel-former	WGA NG-1	kg/m^3	3.6
Demulsifier	NG NE-1	l/m^3	1.0
Clay stabilizer	NG CS-2	l/m^3	1.0
Encapsulated breaker	NG B-1	kg/m^3	0.3 – 1.0
Delayed x-linker	NG XL-2	l/m^3	3.2

All of the presented chemical reagents were used at optimal working concentrations. Guar-based fracturing fluid recipe a system for their staged dosing in accordance with the design of the fracking project at the Vingapurovskoye field, BV_8 formation.

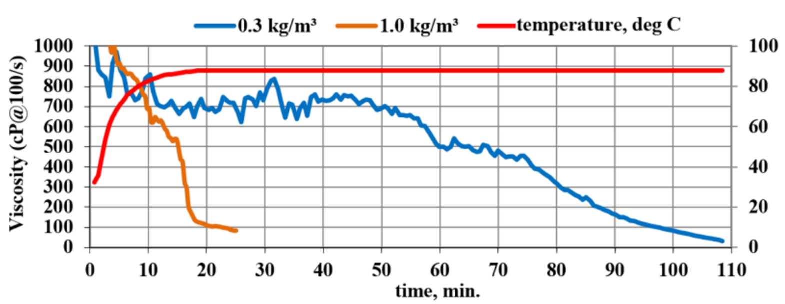

Fig. 1. Rheology of the hydraulic fracturing fluid on the Grace M5600 HPHT rheometer at a shear rate of 100 s^{-1} with varying concentrations of the NG B-1 destructor = 0.3...1.0 kg/m^3

Based on Fig. 1, the thermal stability of the x-linked gel with a loading of destructor NG B-1 of 0.3 kg/m³ was 75 minutes, which meets the requirements for hydraulic fracturing operations. With a concentration of destructor NG B-1 of 1.0 kg/m³, the thermal stability is

16 minutes, making it possible to use this concentration in the final stages of hydraulic fracturing [5].

The recipe of chemical reagents discussed in table 1 allows for the creation of a thermally stable x-linked gel based on guar that has the required injection time margin (20 minutes) for a hydraulic fracturing operation to be successful.

Thanks to the correct technology of conducting fracking and the selection of the necessary chemical reagents with specific concentrations for working on the BV_8 formation, the necessary increase in flow rate in the well is achieved. An analysis based on rheology graphs and the main fracking process showed positive results - the fracture is in an open state and provides an inflow of oil from the formation into the well.

The principles of hydraulic fracturing with a polyacrylamide-based (Co-PAM) fluid are similar to the technology of hydraulic fracturing on a guar basis. All hydraulic fracturing activities are aimed at creating a crack system in an oil reservoir using a thickened liquid, pumping an estimated amount of proppant from the surface into the cracks, fixing it in the reservoir and subsequent destructor of the rupture fluid with its further pumping out to the surface. The main criterion for the success of a hydraulic fracturing operation is the implementation of a planned injection. The polyacrylamide-based gel (Co-PAM) is less viscous with a similar sand-holding capacity compared to the guar system.

In the Co-PAM fluid system, only one reagent is used instead of two, which reduces logistical costs and frees up some of the tanks and pumps in the hydraulic fracturing fleet. This makes it possible to use additional reagents if necessary.

The reagent NG FX-5 is a light-flowing suspension of a rapidly hydrated polyacrylamide copolymer of a branched structure in a hydrocarbon solvent medium.

The main goal of the hydraulic fracturing process is to increase oil recovery from the reservoir by creating a network of fractures and keeping them open using a propping agent, which is transported using viscoelastic fluids. For some companies, the minimum viscosity of the propping fluid based on polyacrylamide (Co-PAM) at which proppant transport is possible is 60 sP (mPa·s). If the viscosity is lower, the hydraulic fracture fluid loses its ability to hold the sand and the proppant particles start to settle, blocking the perforation zone, making it impossible to continue injecting the gel-proppant mix into the formation. Due to these complications, the costs associated with equipment downtime and associated personnel are added to the overall costs of the hydraulic fracturing operation.

The following recipe of polyacrylamide-based (Co-PAM) fracturing fluid was used for the BV_8 formation at the Vingapurovskoye field (Table 2).

Table 2. Recipe of polyacrylamide-based fracturing fluid

Name	Reagent	Unit	Loading
Polyacrylamide	NG FX-5	l/m^3	5.0
Demulsifier	NG NE-1	l/m^3	1.0
Clay stabilizer	NG CS-1	l/m^3	0.5
Encapsulated breaker	NG B-1	kg/m^3	0.3 – 1.0

All of the presented chemical reagents were used at optimal working concentrations. A system of their staged dosing was developed in accordance with the design project of hydraulic fracturing at the Vingapurovskoye field, BV_8 formation.

Based on Fig. 2, the thermal stability of the Co-PAM gel with a loading of destructor NG B-1 of 0.3 kg/m^3 was 70 minutes, which meets the requirements for hydraulic fracturing operations. With a concentration of destructor NG B-1 of 1.0 kg/m^3, the thermal stability is 25 minutes, making it possible to use this concentration in the final stages of hydraulic fracturing [5].

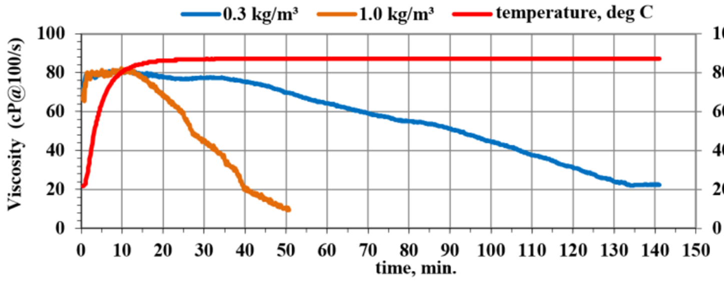

Fig. 2. Rheology of the hydraulic fracturing fluid on the Grace M5600 HPHT rheometer at a shear rate of 100 s^{-1} with varying concentrations of the NG B-1 destructor = 0.3...1.0 kg/m^3

The recipe of chemical reagents discussed in table 2 allows for the creation of a thermally stable Co-PAM gel that has the required injection time margin (20 minutes) for a hydraulic fracturing operation to be successful.

One of the key factors in the success of the fracking process is the quality of the fracturing fluid and its compliance with the requirements of the fracking operation. The use of Co-PAM-based fracturing fluids in the fracking design can significantly improve the filtration properties of the formation due to several factors:

1. High residual permeability of the propping agent.
2. Increased coverage area.
3. Minimum temperature of the base liquid before work: 10-12 degrees Celsius.
4. Lack of sensitivity to bacteria.
5. Reduction of system components.
6. "in-line" operation without a hydration unit.
7. Reduced operating pressure.
8. Compatible with the existing range of destructors.

Fig. 3. X-linked Guar gel

Fig. 4. Co-PAM gel

In Figures 3 and 4, we can see that in the guar-based gel, after the initial crosslinking process, a subsequent reaction takes place, leading to the formation of additional cross-links. This results in a very viscous gel structure, as confirmed by the presence of a wide "tongue".

On the other hand, the Co-PAM-based gel has a reduced viscosity and a more elastic structure, as indicated by the smaller width of the "tongue" and the more uniform distribution of proppant particles.
In the Co-PAM-based gel, the proppant is more evenly distributed, indicating a more homogeneous structure (Fig. 5).

To demonstrate the reverse process of reducing the viscosity of the gels under consideration, tests were carried out on the effect of a persulfate breaker (used at the last stages of the hydraulic fracturing operation) on samples (Figs. 6 and 7).

Fig. 5. X-linked Guar gel (left) and Co-PAM gel (right)

In both cases, gel destruction occurs, which results in a decrease in viscosity and loss of sand-bearing capacity, and as a result, proppant settles to the bottom.

In Figure 7 shows the precipitation of flocculent sediment in a sample with guar gel (left), which can affect the "purity" of the propping agent and worsen the reservoir properties of the producing formation. In contrast, the formation of flocculated precipitate is less likely to occur in the case of polyacrylamide-based fluid (Co-PAM).

Fig. 6. Destruction of X-linked guar gel (left) and polyacrylamide gel (right) by oxidizer breaker

Assessment of the economic impact of implementing a polyacrylamide fluid system in Gel Fracturing Fluid (GFR) was conducted in comparison to a standard stitched guar-borate system (see Tables 1,2 for GFR fluid formulations). As of February 6, 2024, the savings achieved when using the polyacrylamide system amount to 8.5% per cubic meter of GFR fluid.

Fig. 7. Polymer base sediment in guar-based gel (left)

3 Conclusion

For a successful hydraulic fracturing operation, it is essential to carefully select the primary chemical component in the recipe - a gel-forming agent.

The hydraulic fracturing fluid based on Co-PAM has several advantages compared to the guar-based fluid:

1. The Co-PAM fluid is less viscous than the guar gel, which allows for the creation of longer and narrower fractures. This, in turn, can reduce the amount of water produced from a well.
2. Polyacrylamide gels are better at retaining and evenly distributing proppants.
3. Contamination of the fracture with the decomposition products of the fracturing fluid is lower when using Co-PAM, and the clogging of the fracture walls is less than with guar gel.

Additional advantages of the Co-PAM gel system include reduced logistics costs, savings due to less water heating for hydraulic fracturing, elimination of the hydration unit, reduced crew size, decreased wear on pump units, including lower fuel consumption during the hydraulic fracturing operation.

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