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HYDRAULIC FRACTURING PROCESS OPTIMIZATION WITH HYDRAULIC FRACTURING SIMULATOR ON THE EXAMPLE OF FIELD ASAR


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The research work explores and analyzes optimization processing with software on field case using hydraulic fracturing (HF).The article presents hydraulic fracturing in typical production wells and process results for the different designs. The data presented in this article are reflected in the results of the hydraulic fracturing process of the producing well at the Asar field.Hydraulic fracturing of the reservoir was carried out due toa sharp drop in wellproductivity level being at 5.5 m³/day. The reservoir consists of sandstone, siltstone and shale. For well 856, hydraulic fracturing was performed, and as a result, the productivity increase was 4.0 times.

It is necessary to develop a system for optimizing the hydraulic fracturing process, designing and redesigning the best option for the well, investigating the analyses of the projected design, implementing recommendations, and creating a consistent one that allows us to track the obtained parameters and, if necessary, make appropriate adjustments. Implementation of this programming system is crucial for the hydraulic fracturing process. With the software, we can accurately analyze our process to observe real-time fractures and development modes.

KEY WORDS: *hydraulic fracturing, fluid viscosity, fracturing fluid, fracturing conductivity, reservoir, proppant, linear and cross-linked gel.*

ҚАБАТТЫ ГИДРОЖАРУ ПРОЦЕССІН СИМУЛЯТОР MFRAC АРҚЫЛЫ АСАР КЕН ОРНЫНДА ОҢТАЙЛАНДЫРУ

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Зерттеу жұмысы қабатты гидрожару геология-техникалық іс-шарасын қолдана отырып, арнайы симулятор арқылы қабатты гидрожару процессін оңтайландыру жолдарын қарастырады. Мақалада өндіру ұңғымаларындағы гидрожару процессі және оған қолданылатын сұйықтың характеристика нәтижелері келтірілген. Бұл Мақалада келтірілген мәліметтер Асар кен орнындағы өндіру ұңғысына жасалған гидрожару процессінің нәтижелері көрсетілген. Қабатты гидрожару ұңғы өнімділігінің күрт түсіп кетуіне, яғни тәулігіне 5,5 м³/тәу болғандықтан жүргізілді. Қабат құмтас, алевролит және саздардан тұрады. 856 ұңғымасы үшін гидрожару жүргізілді, нәтижесінде өнімділік 4,0 есе өсті.

Қабатты гидрожару процесін оңтайландыруға, ұңғыманың ең жақсы нұсқасын жобалауға және қайта жобалауға, жобаланған жобаның талдауларын зерттеуге, ұсыныстарды енгізуге және алынған параметрлерді бақылауға және қажет болған жағдайда тиісті түзетулер енгізуге мүмкіндік беретін келісілген жүйені құруға арналған жүйені әзірлеу қажет. Бұл бағдарламалау жүйесін енгізу фрекинг процесі үшін өте маңызды. Бағдарламалық жасақтаманың көмегімен біз нақты уақыттағы алшақтықтар мен даму режимдерін бақылау арқылы процесті дәл талдай аламыз.

***ТҮЙІН СӨЗДЕР:** қабатты гидрожару, сұйықтық тұтқырлығы, фрекинг сұйықтығы, фрекинг өткізгіштігі, өнімді қабат, проппант, сызықтық және айқаспалы гель.*

ОПТИМИЗАЦИЯ ДИЗАЙНА ГРП ПОСРЕДСТВОМ ПРИМЕНЕНИЯ СИМУЛЯТОРА MFRAC НА ПРИМЕРЕ МЕСТОРОЖДЕНИЯ АСАР

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Рассматривается и анализируется процесс оптимизации с помощью программного обеспечения на примере месторождения с использованием гидравлического разрыва пласта (ГРП).

Приводятся результаты процесса гидроразрыва пласта в добывающих скважинах и характеристики применяемой к нему жидкости. Данные, приведенные в данной статье, отражены в результатах процесса гидроразрыва добывающей скважины на месторождении Асар. Гидроразрыв пласта проводился из-за резкого падения производительности скважины, т. е. 5,5 м³/сут. Пласт состоит из песчаника, алевролита и сланца. Для скважины 856 был проведен гидроразрыв пласта, в результате чего производительность увеличилась в 4,0 раза.

Даны рекомендации о необходимости разработать систему оптимизации процесса гидроразрыва пласта, проектирования и перепроектирования наилучшего варианта *скважины, изучить анализы проектируемого проекта, внедрить рекомендации и создать согласованную систему, которая позволит нам отслеживать полученные параметры и, при необходимости, вносить соответствующие коррективы.*

Внедрение этой системы программирования имеет решающее значение для процесса гидроразрыва пласта. С помощью программного обеспечения мы можем точно анализировать наш процесс, наблюдая за разрывами в режиме реального времени и режимами разработки.

КЛЮЧЕВЫЕ СЛОВА: *гидравлический разрыв пласта, вязкость жидкости, жидкость для гидроразрыва, проводимость гидроразрыва, коллектор, проппант, линейный и сшитый гель.*

Introduction. When developing oil and gas fields, there is a need to increase production efficiency. This is achieved through a set of measures aimed at improving oil recovery, which includes various technological techniques and methods. Existing technologies can be categorized into volumetric and local methods of impacting the reservoir. Volumetric methods affect the entire deposit or specific development objects, often involving numerous wells. In contrast, local methods are intensification techniques that target specific wells under specified conditions [1].

Therefore, in this research work, the main emphasis is directed to the following stages, according to the scheme in *Figure 1*, the details of which are disclosed in further sections and chapters:

- creation of a geomechanical and petrophysical model of the reservoir near the well;
- creation of a model on software - introduction of known and expected parameters in software (software);
- conducting laboratory tests;
- analysis of pressures and other results;
- forecast of production after hydraulic fracturing [2].

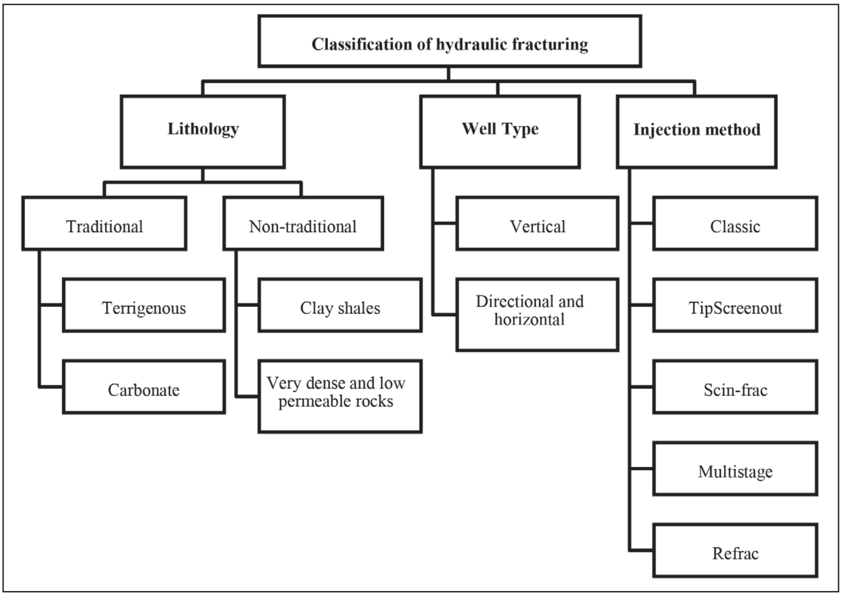

Figure 1 – **Basic classification of hydraulic fracturing [3]**

In hydraulic fracturing, various chemical reagents are utilized to create hydraulic fracturing fluids. The main challenge lies in selecting the most optimal fluid for specific conditions. The difficulty often arises from determining the ideal composition of components, suitable concentrations, laboratory research methods based on reservoir conditions, hydraulic fracturing injection technology, and other factors. By organizing data, classifying components, defining conditions and criteria, and selecting appropriate laboratory analyses, the process of choosing hydraulic fracturing fluids can be simplified [3].

To address this issue, a series of laboratory tests were chosen and conducted to identify a suitable reagent for specific conditions. The necessary reagents were carefully selected, and the requirements for the hydraulic fracturing fluid were established. To illustrate the methodology, a specific fluid selection problem for particular conditions was resolved [2]. It is believed that this method can be applied to different reservoirs, wells, and technological conditions for the selection and customization of hydraulic fracturing fluids. Each reagent was chosen based on scientific and practical considerations [4].

Various tests were performed, including determining the thermal stability of the gel, gel sensitivity, and break stability using a Chandler 5550 rotary viscometer. Additionally, several other tests such as emulsion destruction, water composition analysis, cross-linking time determination, pH measurement, and viscosity assessment under atmospheric conditions were conducted.To meet the above conditions, it is necessary to synchronize the characteristics of hydraulic fracturing fluid by considering many factors at the same time and selecting the necessary components to adjust certain characteristics [5].

As a test of this method, an example of solving a similar problem involving the selection of hydraulic fracturing fluid for oil and gas fields in Asar, which are trapped in Jurassic Terrigeneous clastic sediments, is being considered.

Methodology. Researches show that when selecting the optimal hydraulic fracturing fluid, its formulation must meet the following technological and geological conditions [1]:

• Hydraulic fracturing fluid should preserve the original filtration and reservoir characteristics of the formation as much as possible.

• Have low filtration characteristics in the formation to reduce its penetration through the crack walls.

• Be compatible with the formation fluid to reduce the formation of stable emulsions.

• Be compatible with reservoir minerals, such as clays, to prevent their swelling and blockage of pores.

• Hydraulic fracturing fluid should be easily and as quickly as possible removed from the reservoir during development.

• After the end of the proppant injection, the gel should collapse in a certain time, reducing its viscosity to the required values.

• After destruction, leave behind a minimal sediment.

The recent development of environmentally friendly, polymer-free fracturing fluids, with superior operational performance, represents a major technological advance in the petroleum industry. The use of these new fluids during fracturing operations brings several benefits: minimized environmental footprint and formation damage, operational efficiency and simplicity, and maximized fracture conductivity [6].

Figure 2 – **Chandler Engineering Model 5550 High Pressure High Temperature Viscometer**

Each reagent was selected by scientific and practical justification. The methods used were gel thermal stability, gel sensitivity, and stability to breakdown conducted on a Chandler 5550 rotary viscometerin *Figure* 1. In addition, many tests such as emulsion breakdown test, water composition, crosslinking time, pH metrology, atmospheric viscosity were carried out.

The properties and parameters of the deposit and well are given in *Table 1*. Hydraulic fracturing was successfully carried out in this well by pumping 40 tonnes of proppant and obtaining a fourfold increase in production. The choice for hydraulic fracturing fell due to the presence of a large skin factor, as well as the potential of the well to increase the flow rate due to hydraulic fracturing.

Table 1 – **Reservoir and well parameters**

Parameters	Data
Skin Factor	2
Perforation interval	2026 – 2044 m
Formation capacity	18 m
Formation temperature	88
Reservoir pressure	195 atm
Average permeability	16 mD
Average porosity	16%
Water saturation	30 %
Carbonate content	1%
Petrographic description	The sandstone is gray, medium-fine-grained with clay cement. Clay minerals chlorite, muscovite, kaolinite, biotite are present in the vapors.
Tubing diameter	89 mm
Reservoir fluid	oil+water

In addition to the need to consider the properties and parameters set by the reservoir and the well (*Table 1*), it is also necessary to take into account the technological parameters of hydraulic fracturing injection. Based on the design of hydraulic fracturing, the main technological conditions for hydraulic fracturing fluid have been identified, which are summarized in *Table 2*. These conditions are characterized by values for which it is necessary to select the desired liquid composition.

Hydraulic fracturing programs frequently employ extensive clay control measures to prevent damage from clay swelling subsequent to fracture stimulation. Operators interested in reducing costs associated with the use of clay control additives and possibly the use of oil-based fluids question whether these measures are necessary. Procedures are discussed that may be used to determine the water sensitivity of a given formation. Examples are presented of fluid changes resulting from laboratory studies. General procedures used to determine if rocks require clay control are as follows: determine the mineralogy of formation cores to ascertain if fresh water-sensitive minerals are present, conduct immersion testing of sample chips in a variety of fluids to determine if any physical reaction (disaggregation) is observed. This testing will provide information regarding the salinity requirements of fluids that contact rocks and may be considered "worst-case" information, and select fluids and cores for use in flow testing. The laboratory results of the selection and mineralogical analysis of the basic fracturing fluid are presented below [7].

Table 2 – **Required process conditions for hydraulic fracturing fluid**

Date of test request	-----------------
Horizon (reservoir)	J-9b, J-10a (X)
Reservoir temperature	90 °C
Surface temperature	25 °C
Time to perforation	4 min
Duration of main fracturing	30 min
Loading the gel	no more than 40 g/l
Shift sensitivity	no more than 4 sec
Maximum concentrationof proppant	1200 kg/m^3
Maximum pressure of treatment	400 atm (at the surface)

As you know, there are many different liquid systems for various conditions. So there are slickwater systems, linear gels based on various polymers, crosslinked fluids, viscoelastic surfactants (VES), foams, oil-based solutions. Each of these systems has its own criteria of applicability [5]. A crosslinked gel system based on water-based polymers (crosslinked fluid system) is suitable for our conditions. This is justified by the fact that in this case there is a small (but not micro-permeability) permeability, available chemical reagents on site, logistical nuances, high concentrations of proppant, average injection costs, safety requirements [7].

One of the fundamental factors in the selection of linear and crosslinked gels is the reservoir temperature. It determines the required viscosity of the linear gel, respectively the concentration of the gel forming agent, and in addition, the type and concentration of the crosslinking agent. Gels based on polysaccharides crosslinked with borate crosslinkers are known to have a temperature range up to 150°C. In our case, a linear gel based on modified polysaccharides with a concentration of 3.6 kg/m^3 was selected for 88°C (*Table 3*), which is crosslinked by adding a borate crosslinker with a concentration of 4 l/m^3. This concentration of crosslinker allows the viscosity of the crosslinked gel to hold for the required time, which was substantiated by performing a thermostability test (*Figure 3*). The thermal stability test was performed on a Chandler 5550 rotational viscometer (*Figure 1*), which allows simulating downhole conditions, namely, keeping the gel temperature at 105°C, and simultaneously taking multiple measurements such as shear rate, viscosity and other required parameters. The criterion for the gel to pass the test is the ability to maintain a gel viscosity greater than 400 cP at a shear force of 100 sec^{-1} for the duration of the main fracturing injection.

The complex rheological behavior of crosslinked fracturing fluids is a function of shear history, temperature, and chemistry. Understanding the relationship between these variables and the downhole properties of the fracturing fluid is a challenging task. Rheological measurement techniques are presented that unravel some of the mystery associated with crosslinked fracturing fluids [2,3]. The concept of a physical gel-point for fluids undergoing crosslinkingis introduced and shown to correlate strongly with the proppantcarryingability of the fluid. The gel-point variation with temperature and chemistry is discussed. This variation can be studied in the laboratory to provide an in-situ field performance evaluation without the need for expensive proppant-transport flow loops. The limitations for newly developed, low-concentration polymer fluids are also discussed. The fluid system chosen for analysis was the pHactivated, borate-crosslinked hydroxypropylguar (HPG) fluid [5].

Table 3 – **Water quality analysis**

Determinable parameters	Units of measurement	Analytical results (quantitative values)	Permissible limits
Temperature	°C	24.8	18-42
Specific gravity	(g/cm^3)	1.0	
pH	7.2	5 – 7.9	
Total iron (Fe)	(mg/l)	0.4	<8
Total hardness	(mg/l)	127	<600
Bicarbonates	(mg/l)	109	<600
Chlorides	(mg/l)	65	<1000
Sulphates	(mg/l)	75	<200
Calcium	(mg/l)	-	
Magnesium	(mg/l)	-	
Sodium	(mg/l)	-	
Potassium	(mg/l)	-	
Barium	(mg/l)	-	

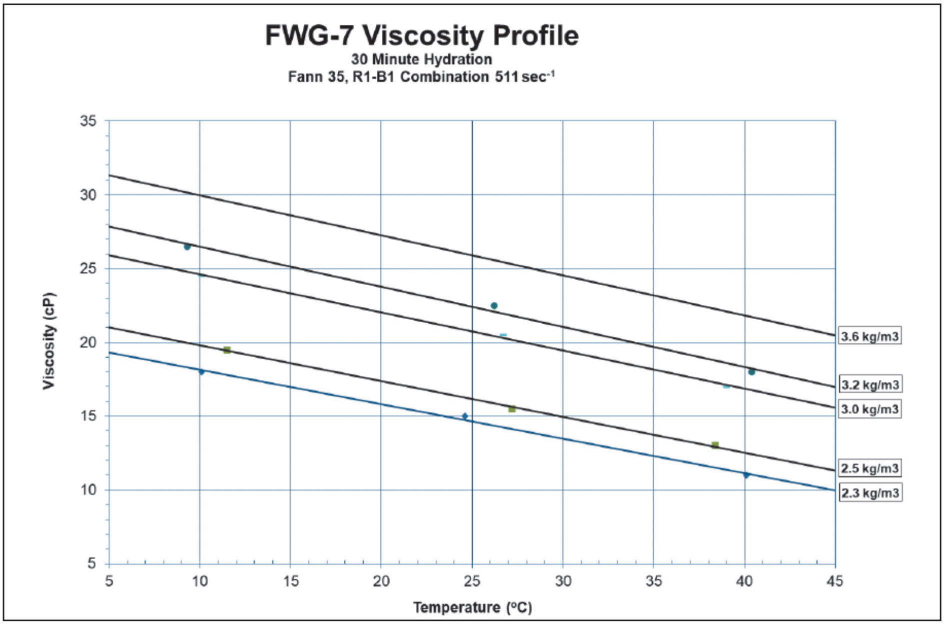

Figure 3 – **Viscosity profile of frac fluids**

Table 4 – **Linear gel quality analysis**

Linear gel, guar concentration 3.6 kg/m³			
Determinable parameters	Units of measurements	Analytical results (quantitative values)	Permissible limits
Temperature	°C	25.0	≥20 (25-35°C)
Viscosity	cP	28	From the viscosity 9 (figure 3)
pH	-	8.0	5.0-8.0

Table 5 – **Quality analysis of cross-linked gel**

Crosslinked gel: guar concentration 3.6 kg/m³, crosslinker concentration 2.5 l/m³ / 1.0 l/m³, breaker concentration from 1.0 to 3.0 l/m³, breaker activator concentration from 1.0 to 2.0 l/m³, clay stabiliser demulsifier concentration 1.5 l/m³		
Determinable parameters	Units of measurements	Analytical results (quantitative values)
Funnel closing time	Sec	10-15
Time for complete crosslinking (lip formation)	Sec	45-50
Temperature	°C	25.2
pH	-	9.0

Results and discussion

For testing on the HPHT rheometer "Chandler" configuration R_1/B_5

Test 1. Test to determine the stability of the crosslinked gel at a reservoir temperature of 88°C.

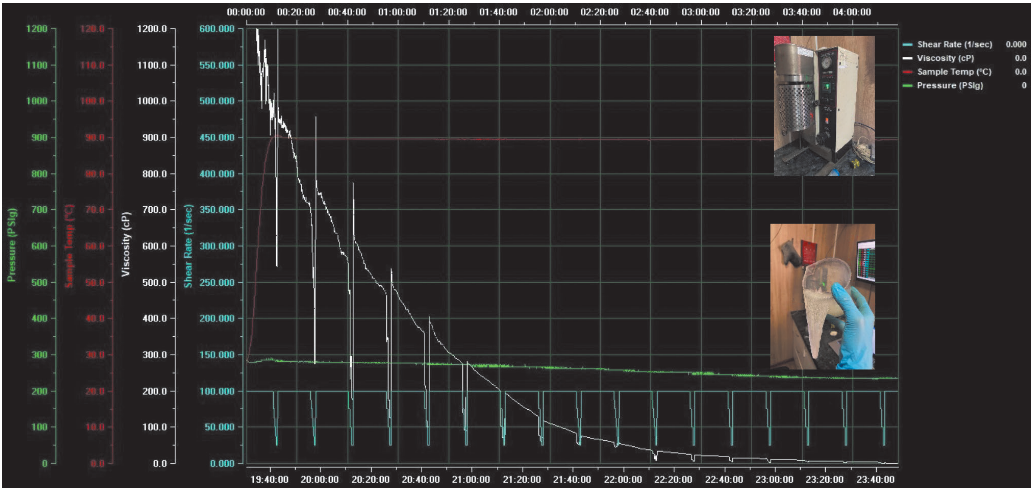

Figure 4 – **Test 1: Test to determine the stability of the cross-linked gel at a reservoir temperature of 88°C**

The viscosity (*figure 5*, white line) of the fluid of the system used for hydraulic fracturing at a reservoir temperature of 88°C should be at least 400 cP with a shear rate of 100 sec^{-1} after the expiration of the testing period equal to "Hydraulic fracturing time × 1.2" – the pillow stage with a minimum concentration of breaker – 1.0 l/m^3.

The viscosity of the cross–linked gel system is more than 400 cP (Tres. = 88°C, the shear rate is 100 sec^{-1}) is observed during the registration period from 0 to 62 minutes. The viscosity of the system at the end of the experiment (233 min) is - 0 cP.

For hydraulic fracturing fluid at a temperature of (80°C), the viscosity should be at least 400 cP with shear strength (Shear rate, sec^{-1}) 100 after the test period is equal to "2/3 Hydraulic fracturing Time" when a breaker with an increased concentration of breakers – 2.0 l/m^3 and1.0 l/m^3.

The viscosity of the cross–linked gel system is more than 400 cP (the increase of the destructor is 2.0 l/m^3, the activator of the destructor is 1.0 l/m^3, Tpl - 80°C, the shear rate is 100 sec^{-1}) is observed during the registration period from 0 to 151 min. The viscosity of the system at the end of the experiment (265 min) is – 0 cP.

Test 2. Test for the restoration of cross-linked properties during cooling

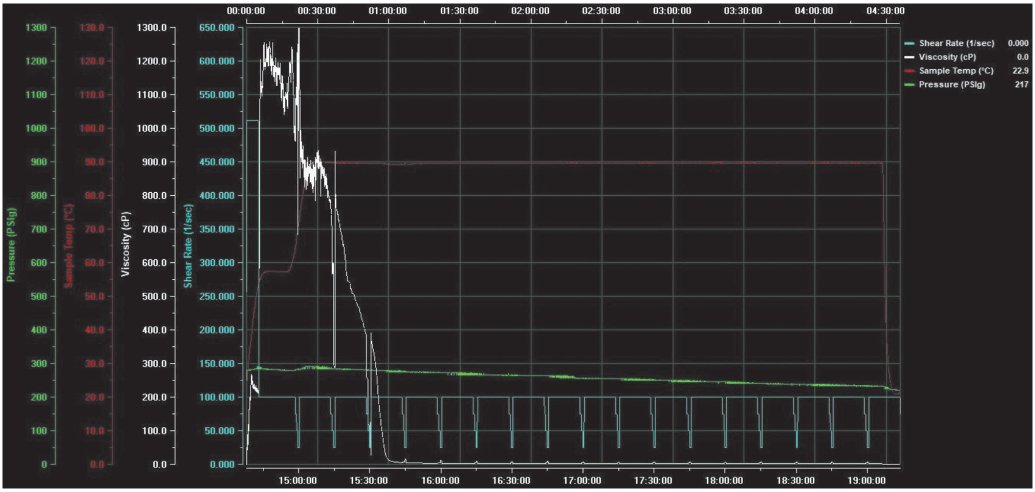

Figure 5 – **Restoration of cross-linked properties during cooling**

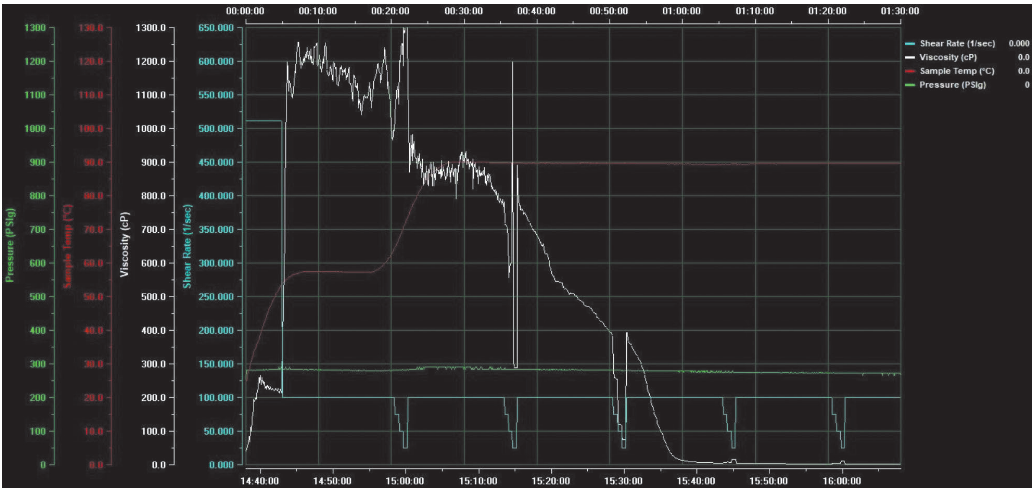

Figure 6 – **The interval from 0 to 50 minutes of the test time**

The viscosity of the cross–linked gel system is more than 400 cP (the increase of the destructor is 3.0 l/m^3, the activator of the destructor is 2.0 l/m^3, Tres. = 88 °C, the shear rate is 100 sec^{-1}) is observed during the registration period from 0 to 41 min. The viscosity of the system at the end of the experiment (227 min) is – 0 cP.

Test 3. Shift sensitivity test (5 minutes for 511 seconds^{-1}, 10 minutes for 100 sec^{-1}) at a temperature = (Tres.+ Tcl.) / 2 = 59.5 ° C – pad stage with a minimum concentration of breaker - 1.0 kg/m

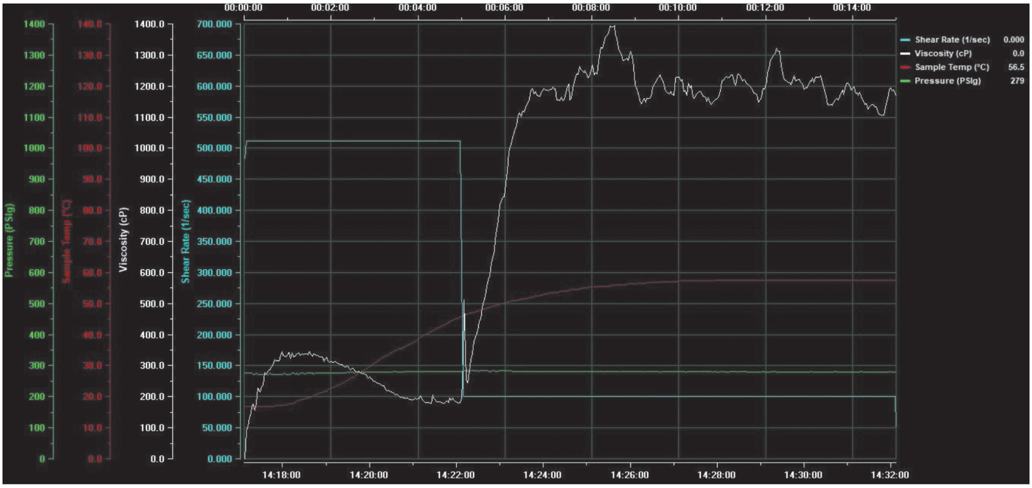

Figure 7 – **Shift sensitivity test**

The sensitivity of the crosslinked gel system (destructor – 1.0 l/m^3, (Tres.+Tcl.)/2 = 59.5 °C, shear rate – 100 sec^{-1}) to shear is very low – the viscosity is restored to 400 cP within 5 sec.

Test 4. Shear sensitivity test (5 minutes for 511 seconds^{-1}, 10 minutes for 100 seconds^{-1}) at a temperature = (Tres.+ Tcl.) /2 = 59.5 °C of liquid with an increased concentration of breaker - 3.0 kg/m^3 and 2.0 breaker activator l/m^3.

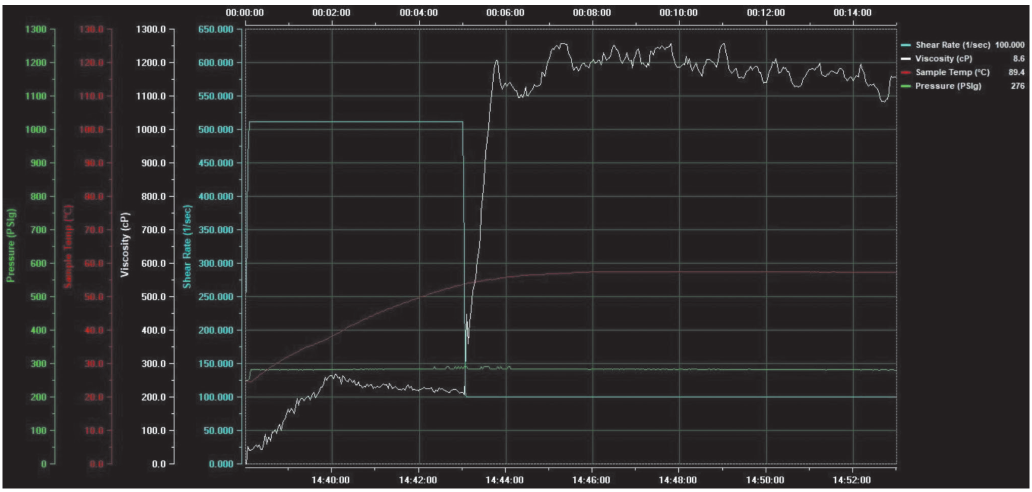

Figure 8 – **Shift sensitivity test (1)**

The sensitivity of the cross–linked gel system (destructor – 3.0 l/m^3, destructor activator – 2.0 l/m^3, (Tpl.+Tp.) /2 = 59.5 ° C, shear rate - 100 sec^{-1}) to shear is very low – there is a recovery of viscosity to 400 cP within 15 sec.

Proper screening of the chemical additives used in a fracturing fluid recipe is imperative in enhancing posttreatment cleanup and well productivity. Selection of the right addtives and dosing should therefore follow a methodical approach that can be replicated and used for the screening of any fracturing fluid additives. [7]

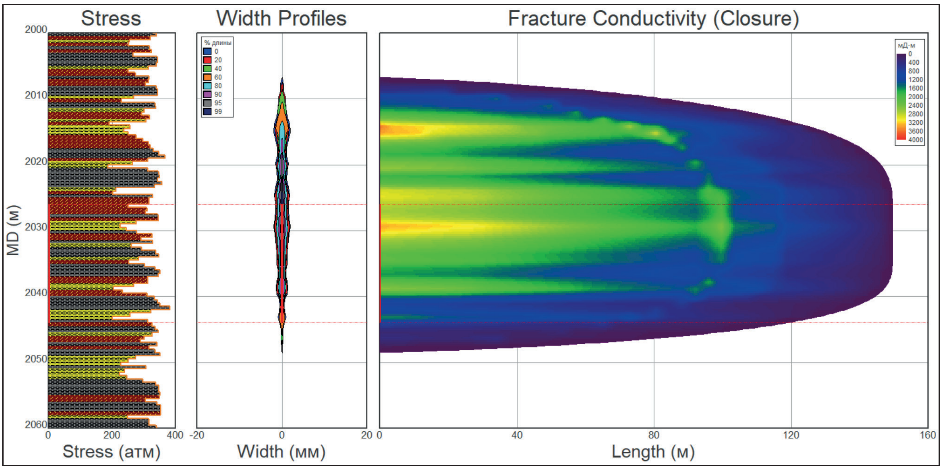

Figure-9 – **Fracture profile after hydraulic fracturing with the use of hydraulic fracturing fluid**

Figure 9 shows the profile of the crack created on the basis of this hydraulic fracturing fluid. The work is considered successful.

• As can be seen from the *figure 9*, the fracture profile has different geometrie in both length and width. These value depend on rock properties, lithology and the amount of proppant injected. The lithological composition of the reservoirs is the same (yellow-sandstone, red-siltstone, grey-shale).

• As can be seen from the table the created fracture length is 150.44 m, width - 11.923 mm, height - 35.229 m, dimensionless fracture conductivity - 0.95 respectively for well 856.

• As shown in *Table 6* for well 856, the skin factor decreased from 0 to minus (-) 4.66 and the oil flow rate increased from 5.5 tonnes per day to 21.6 tonnes per day, thereby increasing the oil flow rate by 16.1 tonnes per day.

Table 6 – **Parameters before and after hydraulic fracturing of well 856**

Parameters	before Frac	after Frac
Skin	0	-4,66
Water Cut, %	88	54
Dimensionless PI	0,16	0,62
Productivity Index, m^3/day/atm	0,403	1,576
Liquid rate, m^3/day	12,1	47,3
Oil rate , t/day	5,5	21,6
Incremental Oil rate, t/day		16,1

Conclusion

• On the basis of a qualitatively selected gel, which was justified by many parameters and characteristics, successful work on hydraulic fracturing was carried out. The optimal formulation of hydraulic fracturing fluid has been selected for work at high temperatures of Jurassic terrigenous formations, in particular at 88°Con depths of more than 2060 m .

• A water-based cross-linked polymer gel system was chosen as such a liquid. Modified polymers were used as a gel-forming agent, which were cross-linked with a borate stapler. The gel was destroyed by ammonium persulfate(NH4)2S2O8). Control of the remaining required properties was carried out by additives of clay inhibitors, pH regulators, biocides, demulsifiers.

• Fracture it was successfully created within the framework of a given design: it had a half-length of about 150 m, a height of about 35 m, was limited at the level of the perforation interval, did not go into the water zone.

• As a result of hydraulic fracturing, the flow rate of this well has increased several times compared to the work before hydraulic fracturing. The result of hydraulic fracturing lasted more than 1.5 year.

• Thus, despite the fact that there are many other factors in hydraulic fracturing technology that affect the final result of work, the rupture fluid is one of the most important. Therefore, the most complete analysis when selecting the liquid helped to carry out this work effectively.

This hydraulic fracturing with the use of such a proppant showed a good result for the conditions of the Asar field.Oil flow rate increased from 5.5 tonnes per day to 21.6 tonnes per day, thereby increasing the oil flow rate by 16.1 tonnes/day. It's good results for Asar field, but such a deposit has an averageflow rate for field is 7-8 tonnes per day.

In the future, it is also necessary to investigate the effect of the salinity of reservoir water on the properties of the rupture fluid.

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