УДК 622.276.66

СРАВНЕНИЕ РАЗНЫХ СЦЕНАРИЕВ ДЛЯ ЖИДКОСТЕЙ ГРП (ГЕЛИ НА ВОДНОЙ ОСНОВЕ И ПЕНЫ) С ПОМОЩЬЮ ЧИСЛЕННОГО МОДЕЛИРОВАНИЯ

COMPARING DIFFERENT SCENARIOS FOR WATER AND FOAM BASE FRACTURING FLUIDS USING NUMERICAL SIMULATION

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Аннотация. В этом исследовании были рассмотрены различные виды базовых жидкостей для гидравлического разрыва пласта (гели и пены на водной основе) для нефтеносного песчаника «Z» на юго-западе Ирана. Целью данного исследования является оптимизация концентрации и вязкости геля в базовых жидкостях и пене, используемых в ГРП. Для этого исследования были разработаны различные сценарии применения различных видов базовых жидкостей, используемых при ГРП. Были оценены значения накопленной добычи нефти и проводимость трещины для каждого сценария. Требуемый объем базовых жидкостей и проппанта были оценены для процесса гидравлического разрыва пласта в исследуемом коллекторе.

Ключевые слова: ГРП, гели и пены на водной основе, вязкость, концентрация геля, накопленная добыча нефти.

Annotation. The goal of this study is optimization of viscosity and gel concentration parameters for water and foam base fracturing fluids in a sandstone reservoir in southwest of Iran. For this purpose various scenarios have been designed based on various kinds of water-base and foam-base fracturing fluids. Then the cumulative oil production has been estimated versus time and fracture half length. In addition the final required fracturing fluid and proppant have been determined for hydraulic fracturing in the studied reservoir.
Also in this research, increasing the cumulative oil recovery for fractured and Non-fractured wells in the studied reservoir have been investigated.

Keywords: hydraulic fracturing, Water base fluid, Foam base fluid, Viscosity, Gel concentration.

Introduction

Currently a lot of fluids are available for hydraulic fracturing. In order to selecting the most appropriate fracturing fluid for oil and gas wells with special characteristics, should be well understood fluid properties and should be informed about how changes in fluid properties to achieve the desired results. Fracturing fluid is one of the most important components of a hydraulic fracturing operation. Its most important effects are opening the fracture, crack extension and proppant transferring into the fracture channels. After placement of proppants in the fracture and being trapped by the closure stresses, fracturing fluid and its additives are diluted. Then fracturing fluid is spewed out of the fracture channels in order to making flow through the reservoir to the fracture channels. Therefore, hydrocarbons can easily enter the fracture channels [1].

Pilehvari and Clark (1985) used two slot-flow rheometers, one with a rough and one with a smooth surface to study slip flow in hydraulic fracturing fluids. Each slot was equipped with a set of flush-mount pressure transducers to measure pressure drop and a thin-film anemometer probe to measure pressure drop and a thin-film anemometer probe to measure heat transfer at the wall. Experiments with crosslinked gels showed that rough surfaces inhibited wall slippage while smooth surfaces promoted it. Both batch and continuous crosslinked gels showed significantly different shear stress measured with the two rheometers for the same shear rates, a clear indication of wall slip. For batch crosslinked gels, this was confirmed with the results of hot-film anemometry [2].

Powel and McCabe (1997) developed a new, borate-crosslinked hydraulic fracturing fluid system. This new, optimized fluid system provided higher viscosity with lower gelling-agent concentrations compared to conventional, borate-crosslinked fluids. Application of the optimized low-gel borate (OLGB) fluid system at low temperatures was discussed. Viscosity, proppant transport and fluid-loss data of the OLGB fluid system were compared to the conventional borate-crosslinked fluids for hydraulic fracturing. Treatment designs were also presented in their work [3].

Tayal and Kelly (1997) used steady shear rheometry to elicit fundamental information on the capabilities and limitations of enzymes. The effect of commercial and new thermostable enzymes on polymer viscosity was investigated in terms of process variables such as temperature of hydrolysis, pH of solution and enzyme concentration. The commercial enzyme was most effective in degrading the guar at slightly acidic conditions and up to 60°C. Above 60 °C, the extent of hydrolysis of guar solutions decreased. With increasing temperature, enzymatic activity increased but enzyme stability decreased and this balance was critical in determining the extent of viscosity reduction [4].

Putzig and Clair (2007) developed a new delay agent which had hybrid functionality versus previously-reported materials. It delayed viscosity development in fracturing fluids based on guar derivatives crosslinked with a variety of common zirconate and titanate crosslinkers under a wide range of PH. The viscosity development could be optimized by adjusting the concentrations of polymer, crosslinker, and delay additive to give the desired profile for a given hydraulic fracturing application [5].

McAndrew and Fan (2014) discussed arguments for the use of fracturing foam base fluids beyond the under-pressured, dry gas reservoirs where they are already favored, using a model developed at the University of Texas at Austin. The simulation study used reservoir conditions based on available information for the Utica, which was chosen because it is a liquid-rich shale of current interest [6].

Investigating of Hydraulic Fracturing in Oil Reservoir «Z» in Southwest of Iran.

A large number of Iran's hydrocarbon reservoir with oil production dating back of several years, are now in a declining period of their production. This has prompted the authorities and petroleum engineers to use effective methods for increasing production. In addition some reservoirs have the good initial oil inplace but they have not a desirable flow capacity. That is why the well stimulation operations seem to be necessary for increasing the permeability.

Studied field is an asymmetric anticline with a length of 11 km and width of 3 km. This is a single-porosity sandstone field with 16 oil layers. Its oil is a relatively heavy with API grade of 25. Gas-Oil ratio in this reservoir has estimated at 700 scf/STB and oil formation volume factor (FVF) is about 1.4 Rbbl/STB. This is a newly explored oil field and now is in a stage of development.

A summary of the geology and fluid properties of the studied field is presented in Table 1.

Table 1 – Reservoir rock and fluid properties of the studied field

Properties	Value	Properties	Value
API	25	Oil FVF, RbbL/STB	1,4
Total Thickness, ft	642	Oil Viscosity, cp	0,68
GOR, SCF/STB	700	Gas Viscosity, cp	0,021
Rock Compressibility, 1/psi	$2{,}8 \cdot 10^{-6}$	Reservoir Temperature, °F	140
Average Porosity, %	12,5	Bubble Point Pressure, psia	1995
Horizontal Permeability, md	154,55	Average Reservoir Pressure, psia	5290
Vertical Permeability, md	2,1	Oil In Place, STB	$3{,}2 \cdot 10^{8}$
Initial Oil Saturation, %	79		

Three-dimensional structure of the studied oil reservoir with 16 oil layers is presented in Fig. 1.

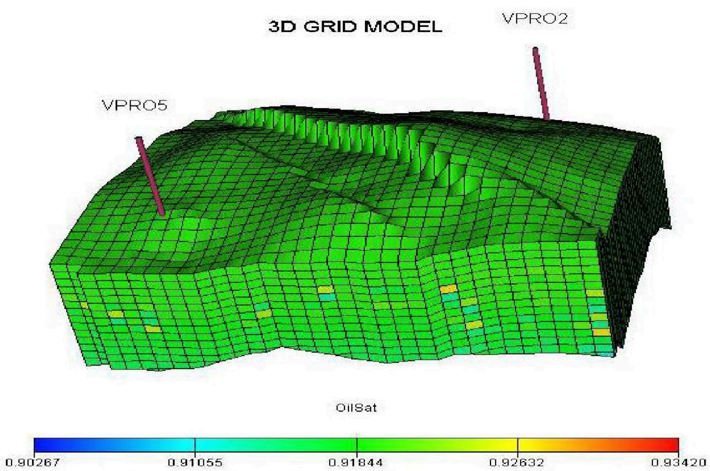

Figure 1 – Three-dimensional structure of the studied oil reservoir in southern Iran

Scenarios of Optimizing the Hydraulic Fracturing Fluid System

In this study various kinds of water base fluids and foam base fluids have been considered for hydraulic fracturing operation in reservoir «Z» in southwest of Iran. The aim of this study is optimizing the viscosity and gel concentration in water base fluids and foam base fluids used in hydraulic fracturing. For this purpose initially various scenarios have been designed for various kinds of water base fluids. Then the cumulative oil production and fracture conductivity have been estimated for each scenario. The scenarios which have had the highest productivity index in studied reservoir have been selected as optimal scenario for selection of fracturing fluids. Also the final required volume of water base fluids and proppant have been estimated for hydraulic fracturing process in the studied reservoir. In this study also various scenarios have been designed for various kinds of foam base fluids. Then the cumulative oil recovery and fracture conductivity have been estimated for each scenario. The scenarios which have had the highest productivity index in studied reservoir have been selected as optimal scenario for selection of fracturing fluids. Also the final required volume of foam base fluids and proppant have been estimated for hydraulic fracturing process in the studied reservoir. The results of this simulation are presented in Tables 2 and 3.

A. Scenarios for water base fluids

In this section water base fluids have been investigated as fracturing fluid. For this purpose various kinds of water base fluids were selected with different rheological properties in terms of viscosity and gel concentration. Then different scenarios have been designed for various kinds of water base fluids for hydraulic fracturing operation in the studied reservoir. Also the cumulative oil production and final required volume of fracturing fluids and proppant have been estimated in each scenario for hydraulic fracturing process applied in the studied reservoir. The scenarios which have had the highest productivity index have been selected as optimal scenario. Also in this study increasing the cumulative oil recovery for fractured and Non-fractured oil wells in the studied reservoir have been investigated. The scenarios for water base fluids are presented in Table 2.

Table 2 – Scenarios for water base fracturing fluids

Water Base Fluid	Np, STB	Visc., cp	Eff. Gel Con., lb/mgal	Tot. Fluid, gal	Tot. Propp., lb
1) 40LB/K HEC W/NO-BREAKER	356713	37	40.2	51725	628037
2) 64LB/K HEC W/NO-BREAKER	414701	132.9	64	87057	1122489
3) 73LB/K HEC W/NO-BREAKER	429395	174.3	73	109650	1433645
4) 77LB/K HEC W/NO-BREAKER	405815	109.9	77.1	79533	1020385
5) 82LB/K HEC W/NO-BREAKER	434783	214.2	82.1	121238	1591438
6) 85LB/K HEC W/NO-BREAKER	437124	240.5	85.1	137921	1822412

For scenario Water base fluid of «73 LB/K HEC w/NO BREAKER» the cumulative oil production versus time and fracture half length is presented in Figures 2 and 3 respectively.

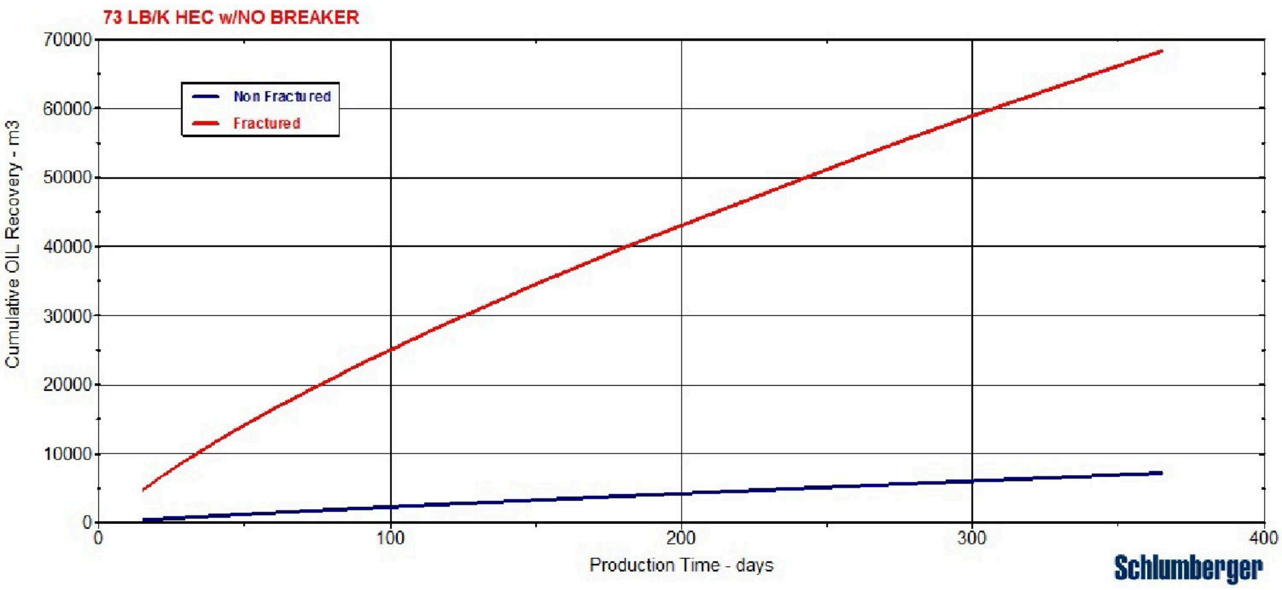

Figure 2 – Cumulative oil production versus time for water base fluid of 73 LB/K HEC w/NO BREAKER

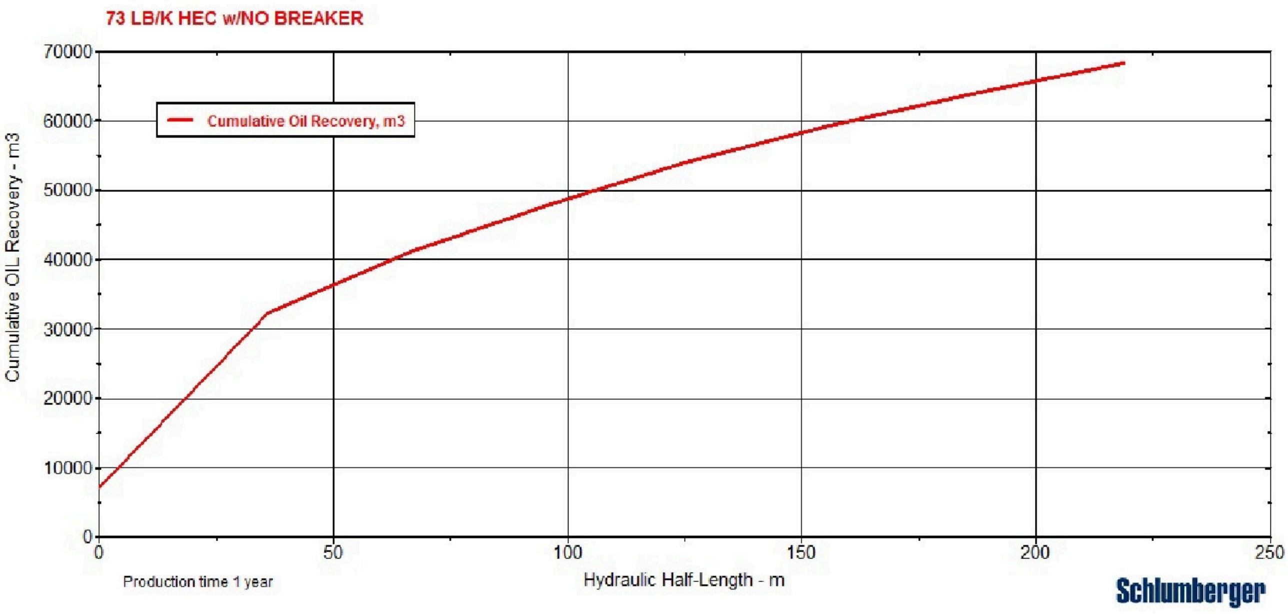

Figure 3 – Cumulative oil production versus fracture half length for water base fluid of 73 LB/K HEC w/NO BREAKER

As it is clear the scenarios of "73 LB/K HEC w/NO BREAKER", "82 LB/K HEC w/NO-BREAKER" and "85 LB/K HEC w/NO-BREAKER" have had the highest cumulative oil recovery than other scenarios. The cumulative oil production for scenario of "73 LB/K HEC w/NO BREAKER" is very close to scenario of "82 LB/K HEC w/NO-BREAKER" and "85 LB/K HEC w/NO-BREAKER". The other hand water base fluid of "73 LB/K HEC w/NO BREAKER" has viscosity less than the two mentioned scenarios. Therefore less frictional pressure drop is created with using water base fluid of "73 LB/K HEC w/NO BREAKER" and so the pumping cost will be reduced. Additionally the gel concentration used for fracturing fluid of "73 LB/K HEC w/NO BREAKER" is less than used in "82 LB/K HEC w/NO-BREAKER" and "85 LB/K HEC w/NO-BREAKER". Hence making cost of "73 LB/K HEC w/NO BREAKER" fracturing fluid is less than "82 LB/K HEC w/NO-BREAKER" and "85 LB/K HEC w/NO-BREAKER" fracturing fluids. Therefore in this study "73 LB/K HEC w/NO BREAKER" fracturing fluid has been selected as optimal fluid between water base fluids for hydraulic fracturing operation in the studied reservoir. Among the reasons for this choice are higher productivity index and lower making and pumping costs.

B. Scenarios for foam base fluids

In this section foam base fluids have been investigated as fracturing fluid. For this purpose various kinds of foam base fluids were selected with different rheological properties in terms of viscosity and gel concentration. Then different scenarios have been designed for various kinds of foam base fluids for hydraulic fracturing operation in oil reservoir "Z". Also the cumulative oil production and final required volume of fracturing fluids and proppant have been estimated in each scenario for hydraulic fracturing process applied in the studied reservoir. The scenarios which have had the highest productivity index have been selected as optimal scenario. Also in this study increasing the cumulative oil recovery in fractured and Non-fractured wells have been investigated in a sand oil reservoir in southwest of Iran. The scenarios for foam base fluids are presented in Table 3.

Table 3 – Scenarios for foam base fluids

Foam Base Fluid	Np, STB	Viscosity, cp	Eff. Gel Conc., lb/mgal	Tot. Fluid, gal	Tot. Proppant, lb
1) WF120 30Q FOAM	230987	23.3	14	37765	401723
2) WF120 50Q FOAM	340598	38.2	10	41713	509252
3) WF120 70Q FOAM	381587	68	6	55976	657229
4) WF140 30Q FOAM	355266	524	28	41440	506236
5) WF140 50Q FOAM	386210	75.8	20	56175	720893
6) WF140 70Q FOAM	413028	128.7	12	76432	962787
7) WF160 30Q FOAM	405326	109.2	42	67975	842196
8) WF160 50Q FOAM	428253	159.5	30	109132	1397326
9) WF160 70Q FOAM	441362	249.5	18	159388	2063004

For scenario Foam base fluid of “WF140 70Q FOAM” the cumulative oil production versus time and fracture half length is presented in Figures 4 and 5 respectively.

As it is clear the scenarios of “WF140 70Q FOAM”, “WF160 50Q FOAM” and “WF160 70Q FOAM” have had the highest cumulative oil recovery than other scenarios. The cumulative oil production for scenario “WF140 70Q FOAM” is very close to scenarios “WF160 50Q FOAM “and “WF160 70Q FOAM”. The other hand foam base fluid of “WF140 70Q FOAM” has viscosity less than the two mentioned scenarios. Therefore less frictional pressure drop is created with using water base fluid of “WF140 70Q FOAM” and so the pumping cost will be reduced. Additionally the gel concentration used for fracturing fluid of “WF140 70Q FOAM” is less than used in “WF160 50Q FOAM” and “WF160 70Q FOAM”. Hence making cost of “WF140 70Q FOAM” fracturing fluid is less than “WF160 50Q FOAM” and “WF160 70Q FOAM” fracturing fluids. Therefore in this study “WF140 70Q FOAM” fracturing fluid has been selected as optimal fluid between foam base fluids for hydraulic fracturing operation in the studied reservoir. Among the reasons for this choice are higher productivity index and lower making and pumping costs.

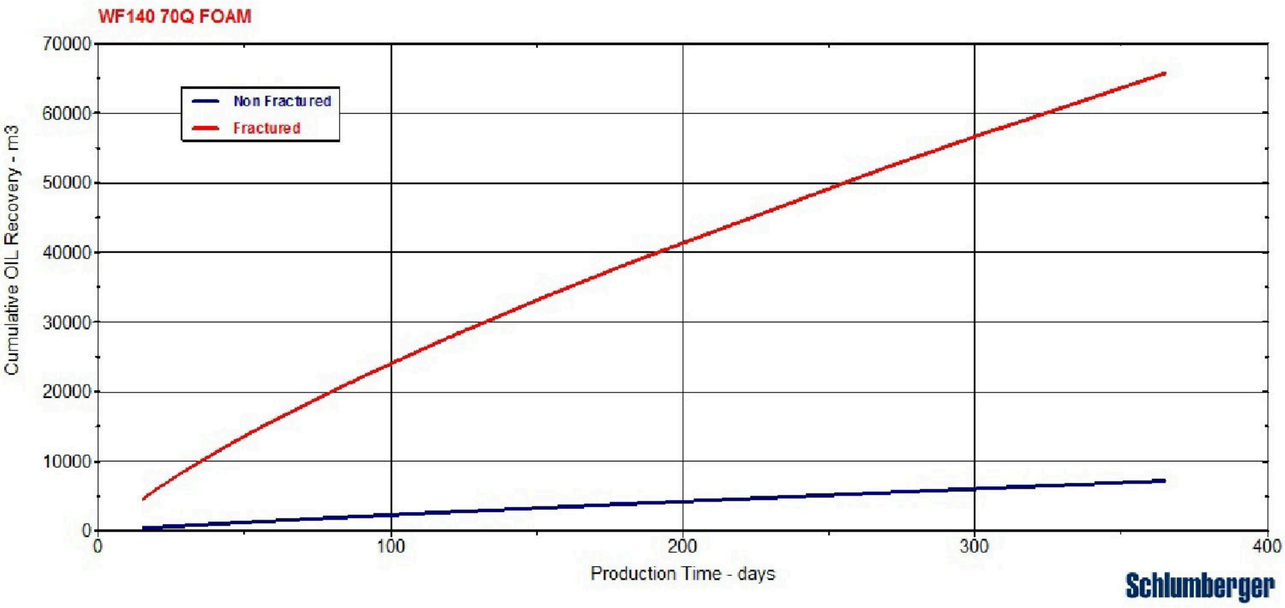

Figure 4 – Cumulative oil production versus time for foam base fluid of WF140 70Q FOAM

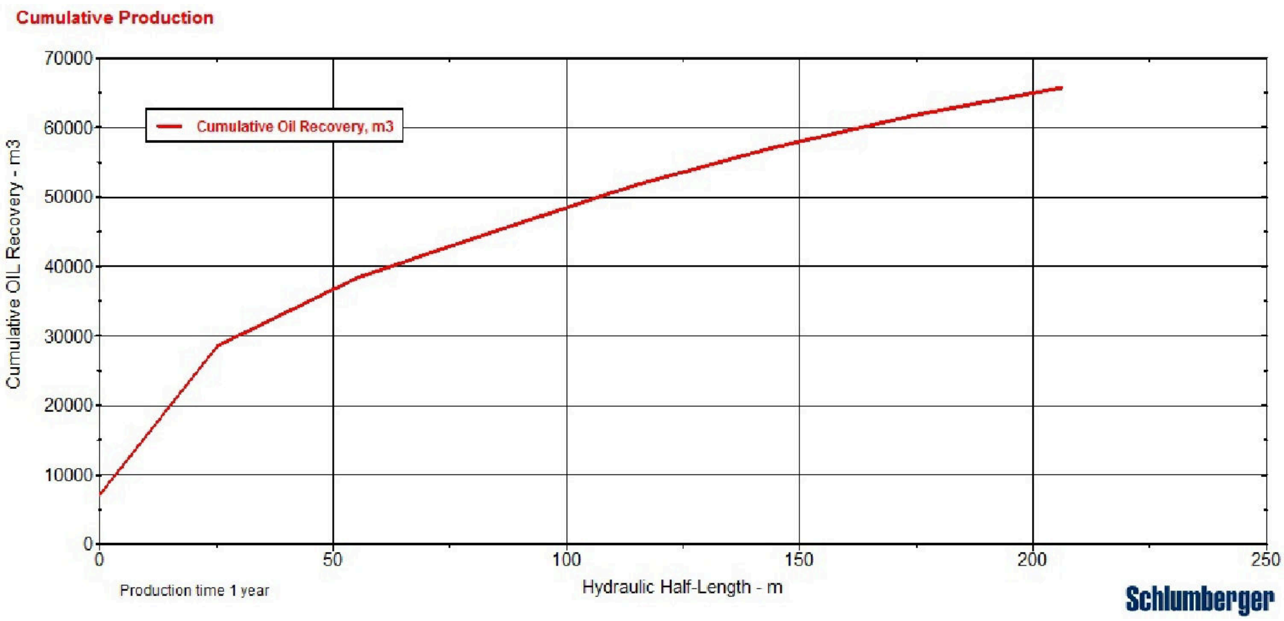

Figure 5 – Cumulative oil production versus fracture half length for foam base fluid of WF140 70Q FOAM

CONCLUSION

1. In this study the hydraulic fracturing process has been caused significant increasing in cumulative oil production in oil reservoir “Z” in southwest of Iran.

2. Fracturing fluids of 73 LB/K HEC w/NO BREAKER, 82 LB/K HEC w/NO-BREAKER and 85 LB/K HEC w/NO-BREAKER have had highest cumulative oil recovery between water base fluids in the studied reservoir.

3. The water base fluid of 73 LB/K HEC w/NO BREAKER has been selected as optimal fracturing fluid in oil reservoir “Z”.

4. Fracturing fluids of WF140 70Q FOAM, WF160 50Q FOAM and WF160 70Q FOAM have had highest cumulative oil production in the studied reservoir between foam base fluids.

5. In this study foam base fluid of WF140 70Q FOAM has been selected as optimal fracturing fluid in the studied reservoir.

RECOMMENDATIONS

Due to the fact that water base fluids have higher performance and also are less expensive, more available, therefore it is recommended that the priority selection of fracturing fluid should be water base fluid in the studied reservoir in southwest of Iran. Also water base fluid of 73 LB/K HEC w/NO BREAKER has higher priority than other water base fluids for hydraulic fracturing operation in the studied reservoir.

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