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Hydraulic Fracturing Length Optimization and its Impact on the Reservoir Performance

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ABSTRACT

Hydraulic fracturing is one of the most common methods of well stimulation for reservoirs with low permeability. Hydraulic fracturing increases the flow capacity, alters flow geometry, bypasses damage and improves recovery factor. The pressure of most of Iranian oil reservoirs is declined and consequently the production is reduced. It is necessary to improve the production by using new stimulation techniques, like hydraulic fracturing. In general, hydraulic fracturing treatments are used to increase the production rate, furthermore increasing recovery factor. In such cases, the fracture length is an appropriate optimization design variable against an economic criterion, e.g., the Net Present Value (NPV). This involves the balancing of incremental future revenue against the cost of operation. The production response in economic terms shows the effect of this design parameter. In this paper, a hydraulic fracturing operation has been designed by the simulator FracCADE 5.1 then its impact on production and ultimate recovery has been investigated by ECLIPSE. According to NPV, the hydraulic fracturing schedule was designed to achieve an optimum fracture half-length.

The results show that hydraulic fracturing increases oil recovery factor and production rate significantly. According to the NPV diagram, the best fracture half-length for AZ-X well is 1100 feet and for MNS-Y well is 900 feet.

Keywords: Hydraulic Fracturing, Optimum Fracture Half Length, Net Present Value, Improve Oil Recovery, Economic Criterion.

INTRODUCTION

Iran has been producing oil for more than 100 years. Most of Iran's fields are mature and it is estimated that 200,000-250,000 bbl/d of crude production is lost annually through natural pressure declines of the fields. Moreover, with available technology, it is only possible to extract 20% to 25% of the original oil in place. Therefore, looking for new technology to sustain and increase the production is unavoidable. Hydraulic fracturing technology is presented as an effective method that can make a difference [1].

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Hydraulic fracturing is now seen as an essential piece of well and reservoir administration and a pillar of production engineering rather than a choice of last resort for depleted or mysteriously underperforming wells. Fracturing has continuously expanded until it has become the completion choice for all types of wells. Possibly, as indicated by Iranian oil reservoir condition, hydraulic fracturing is the appropriate technique to upgrade oil recovery, increase production rate. It can bring back old hydrocarbon fields to life.

The essence of hydraulic fracturing is production improvement, i.e. accelerating production in a depleted drainage area. The question, of course, is whether this acceleration of the production, compared to an unfractured well and evaluated through their respective present values of the revenue streams (one for a fractured well and another for an unfractured well), can be adjusted against the expenses of the treatment. In addition to the increase in production, an assessment of the economics of a hydraulic fracturing treatment must consider many factors, including treatment costs, additional reserves that may be produced before the well reaches its economic limit and reservoir risks associated to mechanical problems that could cause the treatment to be unsuccessful. While there are other criteria for assessing economic attractiveness or lack thereof, for the purposes of this work, we will use the Net Present Value as the criterion for the optimization and the evaluation of the desirability of the specific hydraulic fracture treatment. The NPV criterion has been already selected by several researchers to monetize the incremental production obtained after a fracturing treatment. No matter how sophisticated is the model used to predict fracture propagation and performance, the economic optimization requires a trial and error process to determine the optimum treatment design from a set of the calculated physical designs. According to the studies which done on two reservoirs in Iran, besides selecting the best layer for making fracture, the most optimized case designed and effect of hydraulic fracturing on production studied.

The first commercial hydraulic fracturing treatment aimed to enhance production was conducted in the Hugoton Gas Field in 1947 on Kelpper Well 1. As a fracturing fluid, a gasoline-based napalm-gel was used. However, these unpropped treatments did not increase production leading to the belief that hydraulic fracturing did not represent any improvement in the performance of the wells [2]. In 1949, 11 out of 23 wells where hydraulic fracturing treatments had been applied reported a significant increase in productivity in fields located in Wyoming, Colorado, Oklahoma and Texas [3]. In 1957, mathematical relations between fracturing efficiency, injection rate, pumping time and fracture width were developed to predict fracture extent. This explained why some fluids were more efficient than others and why some pumping rates yielded better results. From this time forward, fracturing treatments changed from an experimental basis to technically-based perspective [4]. Hydraulic fracturing is well-known as a technique to improve productivity in low permeability reservoirs and overcome damage in moderate and high-permeability reservoirs. Hydraulic fracturing provides improved fines control in unconsolidated formations; in addition the pressure drop due to production will be distributed over the surface area of the created surface instead of the surface area of the wellbore or gravel pack radius [5].

EXPERIMENTAL PROCEDURES

Criteria for Selecting a Candidate Well

Choosing an excellent candidate for stimulation results in success whereas choosing a poor candidate leads to economic failure. The mechanical properties can be used in selecting oil and gas wells for fracturing treatments. If these properties are taken into considerations, they will facilitate the task of identifying the proper candidate for this expensive job [6].

Reservoir Permeability

There are several factors which govern reservoir permeability. These factors are lithology, the design of treatment, and available equipment. As these factors differ for different fields so the reservoir permeability also differs. There is not an exact range of reservoir permeability that is appropriate for hydraulic fracturing. Based on experience, there are some classifications which provide a general idea about reservoir permeability for hydraulic fracturing. According to one classification which was based on field experience, good candidates for matrix stimulation are oil reservoirs with a permeability of 10 md or more. For hydraulic fracturing, oil reservoir permeability of 1 md or below is considered a good candidate. If the permeability is between 1 md and 10 md then selecting a suitable stimulation technique is difficult and it needs more study. A permeability less than 0.1 md is a good candidate for gas reservoirs. Other classifications show that a permeability less than 5 md is a good candidate for oil reservoirs whereas less than 0.5 md is appropriate for a gas reservoir [7].

Production History of the Well

It is a good idea to consider the production history of the candidate well and to compare it with the productivity of some of the offset wells. It provides a better understanding of the productivity decline of the candidate well [7].

Oil and Gas in Place Volume, Hydrocarbon Saturation, and Reservoir Pressure

An important factor in the selection of a candidate well for hydraulic fracturing is the volume of hydrocarbons in place. The purpose of hydraulic fracturing is to increase the productivity but, if there is not enough oil and gas then it is not economically viable. For good results, it should have a considerable amount of oil and gas in place and reasonable reservoir pressure. There is no exact value for oil and gas in place, reservoir pressure, and hydrocarbon saturation, but it should be such that doing hydraulic fracturing is economically profitable. Some of the typical values are given in Table 1 [8].

Table1: Typical value of some parameters for hydraulic fracture [8].

Parameter	Oil reservoir	Gas reservoir
Hydrocarbon saturation	> 40%	> 50%
Water cut	< 30%	< 200bbl/ MMscf
Reservoir pressure	< 70% depleted	Twice abandonment press
Gross reservoir height	> 10 m	> 10 m

Two types of characteristic should be considered for a suitable layer for hydraulic fracturing operation. After selecting the suitable well which are Target layers and Barrier layers. Target layer should has characteristics such as high porosity, low in-situ stresses, low water saturation, low and proper uniaxial compressive strength (UCS), and large difference between the minimum and maximum horizontal stresses [9].

Candidate Reservoir General View

Most of Iran›s oil production comes from aging super-giant fields that have been producing for several decades, hence increasingly; they require techniques to sustain production. Although these fields still hold billions of barrels of oil, the production of the remaining reserves needs stimulation methods for improved recovery. Some of the old wells in most part of major fields such as Ahwaz have been cut back and shut-in due to rapid pressure drops and rising water cuts. Since most of the reservoirs in Iran are predominantly made of carbonates, chemical treatment is almost the only reservoir stimulation method that has been conducted routinely in recent decades. Hydraulic fracturing is one of the most effective methods of well stimulation and may have usefulness in these reservoirs if it is designed and executed properly.

Production Forecast and Analysis

The hydraulic fracturing design is completed on the basis of the production forecast and Net Present Value (NPV) analyses. In order to perform Production forecast, Eclipse Simulator was used.

Model Description

The base case is a Cartesian grid dimension 30×30×11, in X, Y and Z directions having the following characteristics. Blocks dimension is 500×500×500 ft, black oil in under-saturated reservoirs. The simulation was run for 4000 days. In this case, one vertical producer was used. Table 2 presented the reservoir parameters used in the model. Refined grid blocks were created around the wells and in the fractured area by using the local grid refinement (LGR) feature in Eclipse. The refinement along the I-direction and J-direction was determined to be NX=9, NY=30, NZ=5.

Table 2: Summary of Input parameters for homogeneous reservoir.

Capillary pressure(psi)	0.00
Permeability(md)	3.00
Porosity	0.10
Initial reservoir pressure(psi)	6300.00
Maximum oil rate(STB/Day)	10000.00
Bottom hole flowing pressure(psi)	1000.00
Radius wellbore (ft)	0.55

Local Grid Refinement Method

LGR method was used to create hydraulic fractures in reservoir simulation model. LGR is a technique within Eclipse which represents the splitting of a coarse grid block into a smaller cell in order to achieve a more detailed simulation in sensitive areas.

Refined grid blocks were created around the wells and in the fractured area by using the LGR feature in Eclipse. The degree of refinement along the wells and in the fracture was determined using sensitivity analyses. The wellbore refinement is specified in eclipse as Nx, Ny, and Nz, which are the level of refinement in I, J and K-direction, respectively. The refinement along the I-direction and J-direction was determined to be Nx=5, Ny=5. This means that the center grid blocks of the fracture LGR, representing the hydraulic fracture itself, is surrounded by 2 gradually refining levels towards the center. The fracture width is 0.5 inch, but for the simulation model, we used a row of cells of 2ft wide to represent the hydraulic fracture in the center-blocks. In addition it will not be practical to refine the grid cells down to the actual fracture width because the wellbore radius was 0.7 ft, and the fracture width had to be higher than this dimension, in order to reduce numerical problems during the simulations. Figure 1 illustrates the center-blocks in the fracture LGR, the hydraulic fracture is represented by a line. However, important parameters such as permeability and porosity of the hydraulic fracture are different from the host cells. This is where the output from the fracture design is applied. Assuming a constant fracture conductivity, the fracture permeability corresponding to a desired fracture grid width can be adjusted and specified in the model using Equation 1.

$$K_{fe} = \frac{K_f \ W}{w_e} \quad (1)$$

where K_{fe} is the equivalent fracture permeability, and w_e is the equivalent fracture width.

The value of the input permeability for the hydraulic fracture has been scaled to preserve the actual fracture designed width and the values of the inputs such as equivalent fracture permeability grid cell were obtained from Equation 1.

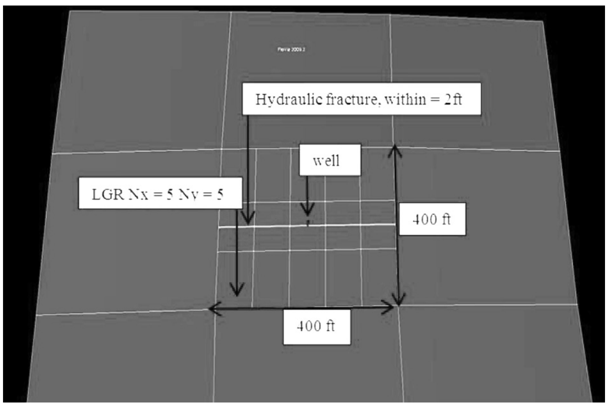


Figure 1: Fracture and wellbore LGR used in the model.

Production Forecast and Net Present Value Analysis for Select Optimum Fracture Half-length

The hydraulic fracturing design is completed on the basis of the production forecast and Net Present Value (NPV) analyses. In order to perform Production forecast, Eclipse Simulator was used. This sensitivity analysis is used to assess the performance of stimulations and guide future design choices.

Project managers, and indeed anyone involved in hydraulic fracturing design must be able to analyze the financial outcome of one's decision. Making a decision requires the measure of performance net present value (NPV), financial analysis methods are tools that enable us to evaluate the total costs and benefits involved in a hydraulic fracturing job in wells. Comparison of the production forecast for the fractured well and the predicted production decline for the unstimulated well allows for calculations of the annual incremental cumulative production for year n for an oil well [10]:

$$\Delta N_{p,n} = N^{f}_{p,n} - N^{nf}_{p,n} \quad (2)$$

$\Delta N_{p,n}$= the predicted annual incremental cumulative production for year n.

$N^{f}_{p,n}$ = the forecasted annual cumulative production of a fractured well for year n.

$N^{nf}_{p,n}$= the predicted annual cumulative production of a non-fractured well for year n.

The annual incremental revenue for the unstimulated well is expressed as:

$$\Delta R_n = (\$) \Delta N_{p,n} \quad (3)$$

where ($) is oil price. The present value of the future revenue is then

$$NPV = \sum_{n=1}^{m} \frac{R_n}{(1+i)^n} - cost \quad (4)$$

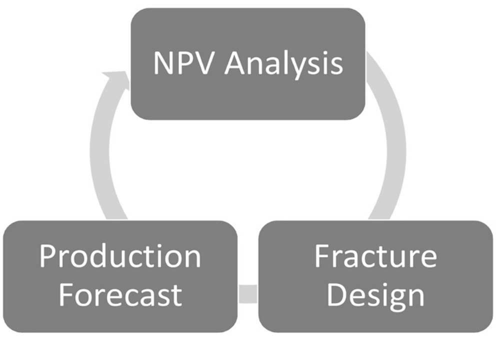
where m is the remaining life of the well in years, and i is the discount rate.

The cost should include the expenses for proppant, fracturing fluid, pumping, and a fixed cost for the treatment job. According to the simulation, proppant will be the major job expenses. A financial analysis was then performed using the present-day crude oil price $30/STB. In addition, a future oil price has been predicted. Some costs and operational parameters are shown in Table 3. All cost values are engineering estimates and near to real costs.

Table 3: Cost of fracture treatment used in the economic study.

Components	Cost
fixed Cost ($)	80000
Proppant ($/lb)	1.1
Fluid ($/gal)	0.69
Pumping Charge(4000-5000 psi)	$ 7/HHP
Pumping Charge(5000-6000 psi)	$ 9/HHP
Pumping Charge(6000-7000 psi)	$ 12/HHP

The treatment schedule is designed for different fracture lengths and the fracture features are estimated by the simulator. Oil production is anticipated in both fractured and unfractured well. So the optimal fracture length has been selected by the NPV graph.



Different scenarios and treatment schedules have been designed to achieve distinctive features of different fracture lengths, then oil production is projected at different scenarios using the Eclipse simulator. With regard to the expenditure and income in various scenarios, NPV is calculated. The best NPVs for all scenarios have been shown in Figure 2 and Figure 3, the best net present value can be obtained from 900 feet fracture half-length for MNS-Y well and for AZ-X well. Also, the NPV increased to 1050 feet fracture half-length and after this, the NPV has not increased significantly. So the optimal fracture half-length for well MNS-Y well is 900 feet, and for AZ-X well is 1050 feet.

Properties of the Optimized Fracture

According to NPV figure for Ahwaz and Mansori reservoir, treatment schedule has been designed to achieve a favorable fracture half-length.

The proppant and fluid have been selected considering the wells and reservoirs conditions. Pump schedule has been designed and hydraulic fracturing operation has been simulated to achieve the optimum fracture length based on Figure 2 and Figure 3. Fracturing fluid plays a vital role in hydraulic fracture treatment because it controls the efficiencies of carrying Proppant and filling in the fracture pad. YF555 fracturing fluid type was chosen for runs. This is one of the fluids included in the model database and is the fluid with the median viscosity. YF555 is a fracturing fluid that has 40 pounds of a polymer per 1000 gallons of water with a Crosslinker added. Proppant must be selected on the basis of in situ stress conditions, According to the ruling of insitu stress in Bangestan Reservoir, Real concerns are compressive quality and the impact of weight on proppant penetrability. Carbolite type proppant has been selected for this simulation. The optimum pump schedule is shown in Tables 4 and 5.

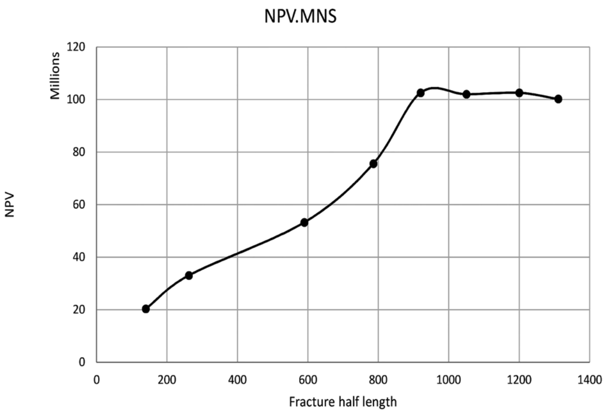


Figure 2: NPV versus fracture length for well MNS-Y.

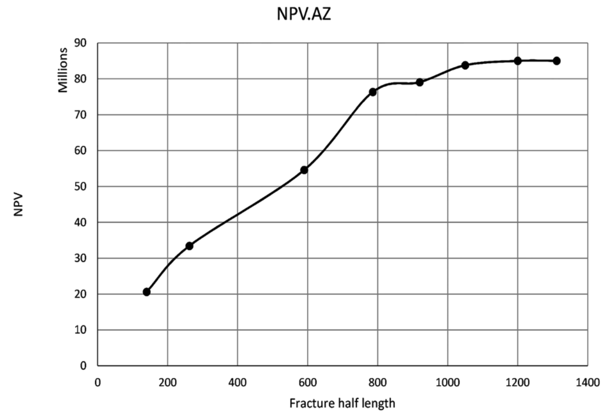


Figure 3: NPV versus fracture length for well AZ-X.

Table 4: Pump schedule for MNS-Y well.

	Stage Name	Pump Rate bbl/ min	Fluid	Fluid Name	Gel Conc. Ib/mgel	Fluid Volume gal	Prop	Prop Conc. PPA	Prob Mass Ib	Slurry Volume bbl	Pump Time min
1	PAD	30.0	4	Prime FRA	30.0	141700	0	0.0	0	3373.8	112.5
2	1.0 PPA	30.0	5	YF555	30.0	3200	3	0.1	3199	78.8	2.6
3	2.0 PPA	30.0	5	YF555	30.0	4000	3	0.2	7998	101.7	3.4
4	3.0 PPA	30.0	5	YF555	30.0	6000	3	0.3	17996	157.4	5.2
5	4.0 PPA	30.0	5	YF555	30.0	7000	3	0.4	27994	189.2	6.3
6	5.0 PPA	30.0	5	YF555	30.0	8000	3	0.5	39991	222.7	7.4
7	6.0 PPA	30.0	5	YF555	30.0	11000	3	0.6	65985	315.1	10.5
8	7.0 PPA	30.0	5	YF555	30.0	12000	3	0.7	83981	353.4	11.8
9	8.0 PPA	30.0	5	YF555	30.0	13000	3	0.8	103999	393.3	13.1
10	FLUSH	30.0	1	2% KCL W	0.0	20686	0	0.0	0	492.5	16.4

Table 5: Pump schedule for AZ-X well.

	Stage Name	Pump Rate bbl/ min	Fluid	Fluid Name	Gel Conc. Ib/mgel	Fluid Volume gal	Prop	Prop Conc. PPA	Prob Mass Ib	Slurry Volume bbl	Pump Time min
1	PAD	30.0	10	Prime FRA	30.0	105000	0	0.0	0	2500.0	83.3
2	1 PPA	30.0	2	YF555	30.0	4000	3	0.1	3999	98.6	3.3
3	2 PPA	30.0	2	YF555	30.0	5000	3	0.2	9998	127.6	4.3
4	3 PPA	30.0	2	YF555	30.0	5000	3	0.3	14997	131.8	4.4
5	4 PPA	30.0	2	YF555	30.0	5000	3	0.4	19996	136.1	4.5
6	5 PPA	30.0	2	YF555	30.0	5000	3	0.5	24994	140.3	4.7
7	6 PPA	30.0	2	YF555	30.0	6000	3	0.6	35992	173.5	5.8
8	7 PPA	30.0	2	YF555	30.0	6000	3	0.7	41991	178.6	6.0
9	8 PPA	30.0	2	YF555	30.0	6000	3	0.8	47999	183.7	6.1
10	FLUSH	30.0	1	2% KCL W	0.0	3386	0	0.0	0	80.6	2.7

The hydraulic fracturing properties have been mentioned in Table 6 and Table 7 and proppant concentration profile for two different wells are shown in Figure 4 and Figure 5.

Table 6: Optimum fracture properties for MNS-Y well.

Hydraulic fracture half length (ft)	1127
Propped fracture half length (ft)	918
Hydraulic height at well (ft)	150
Averaged propped width (in)	0.127
Effective FCD	0.9
Effective conductivity (md.ft)	2188
MAX surface pressure (psi)	8590

Table 7: Optimum fracture properties for AZ-X well.

Hydraulic fracture half length (ft)	1201
Propped fracture half length (ft)	1049
Hydraulic height at well (ft)	81
Averaged propped width (in)	0.122
Effective FCD	0.6
Effective conductivity (md.ft)	1698
MAX surface pressure (psi)	8647

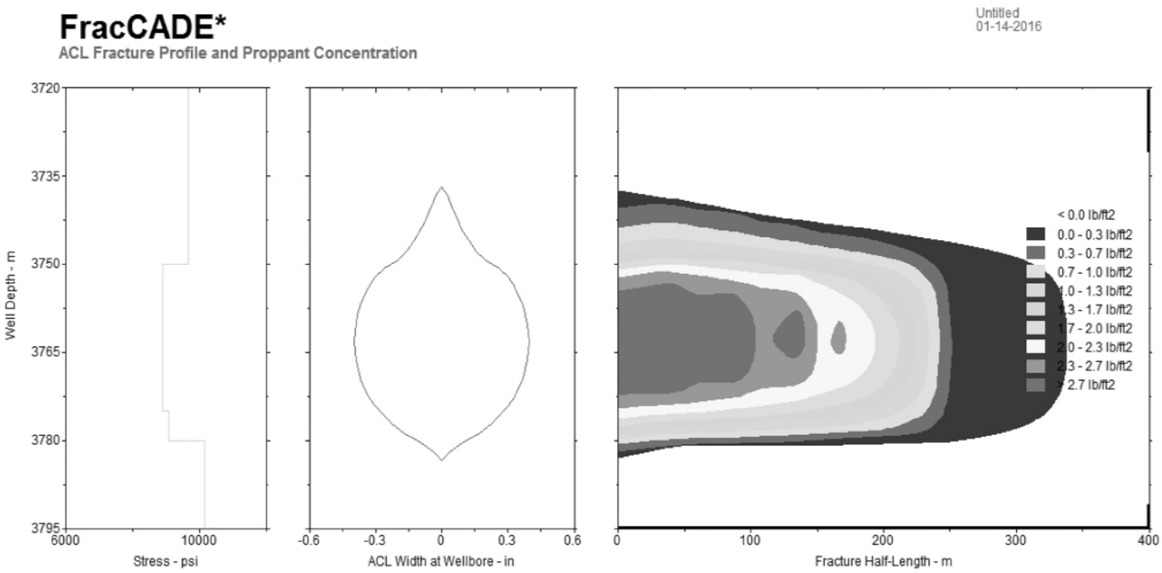


Figure 4: Proppant concentration profile for well MNS-Y.

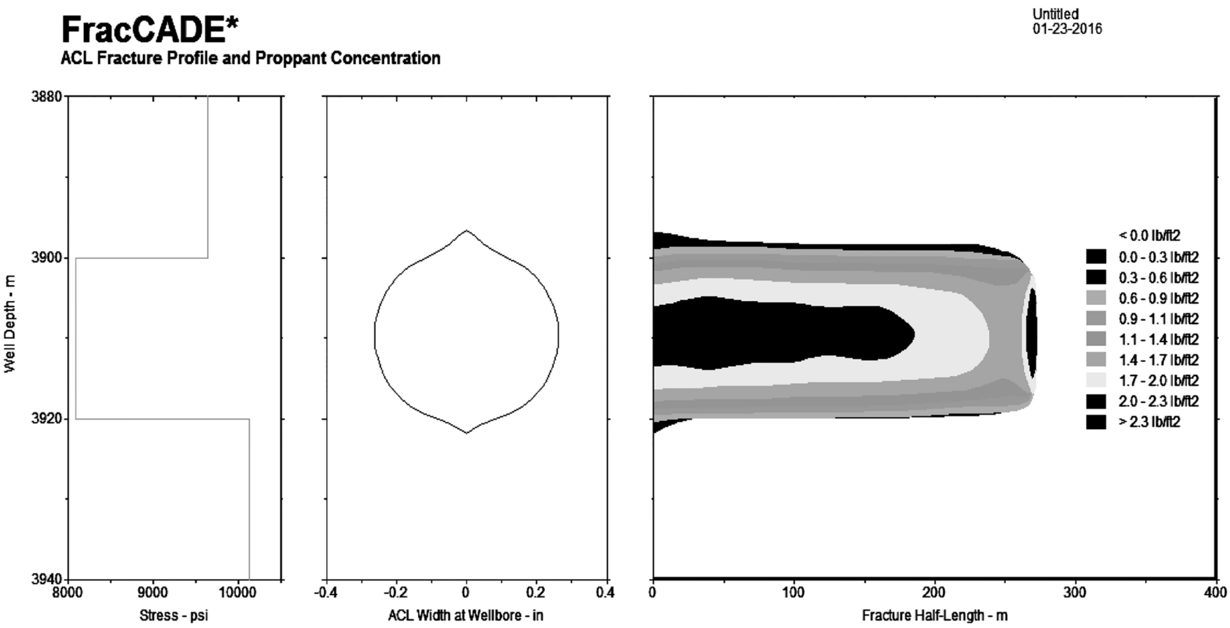


Figure 5: Proppant concentration profile for well AZ-X.

Production Forecast

An unfractured well has been simulated as a base case scenario. Consequently, it's simulation is then compared with the hydraulically fractured well. Both the unfractured well and fractured well had constant formation permeability and constant condition. The main objective of this scenario is to analyze the increase in production of a well fractured with a vertical fracture in relation to unfractured wells. Reservoir with hydraulic fracturing model was made according to the optimum hydraulic fracturing properties.

RESULTS AND DISCUSSIONS

According to Figures 6 to 9, the results show clearly that hydraulic fracturing improves the oil production rate. The connectivity between wells and reservoir was improved Due to the increase of the permeability near the wellbore. Thus, the fluid flow efficiency improved as well.

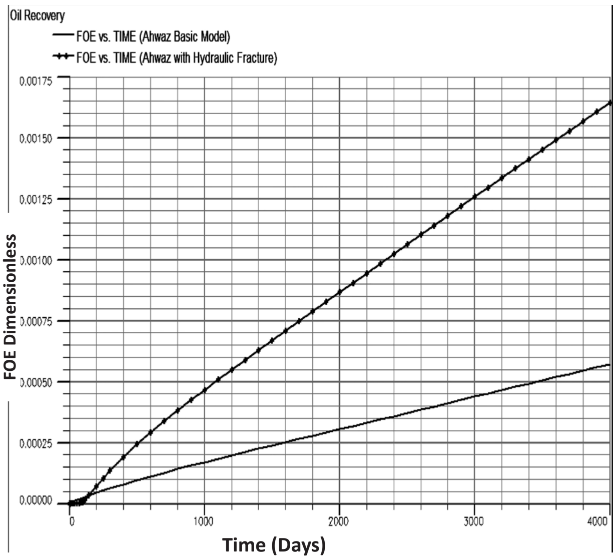


Figure 6: Oil recovery factor for Ahwaz reservoir before and after hydraulic fracturing simulation.

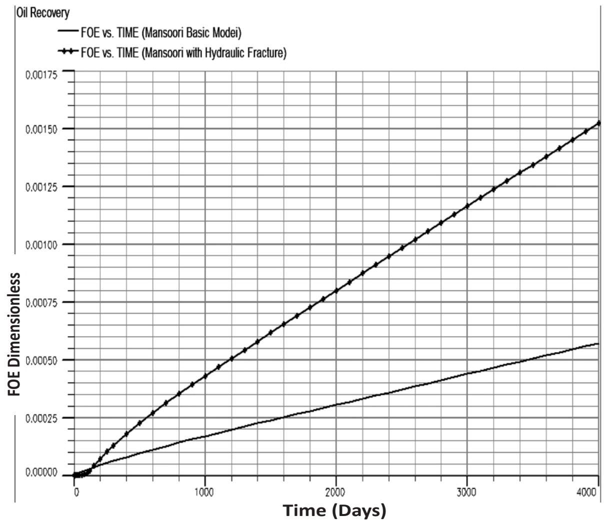


Figure 7: Oil Recovery factor for mansori reservoir before and after hydraulic fracturing simulation.

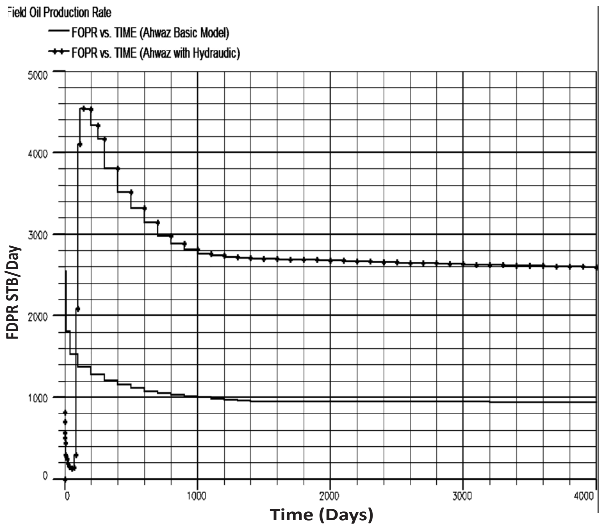


Figure 8: Oil production rate from a vertical well for AZ-X before and after hydraulic fracturing simulation.

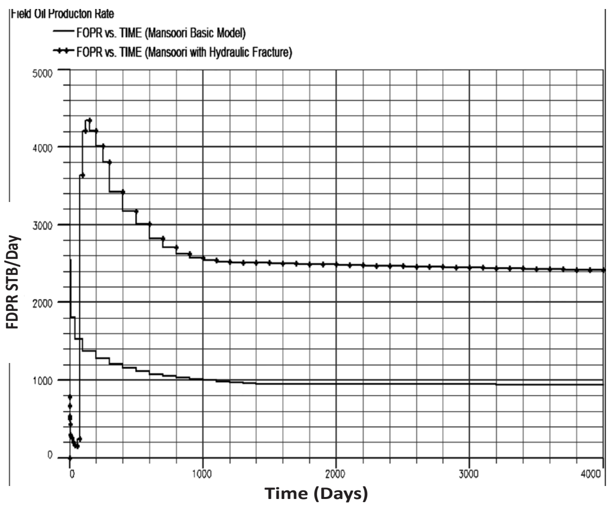


Figure 9: Oil production rate from a vertical well for MNS-Y before and after hydraulic fracturing simulation.

CONCLUSIONS

NPV calculations results confirm the suitability of the procedure presented for the identification of the most profitable fracture half-length to design Pump Schedule to achieve optimum fracture half-length. The case study belongs to two of the Iranian southern oil reservoir selected for the design of hydraulic fracturing operation. The impact of a hydraulic fracturing treatment on the reservoir performance was investigated. The best scenario for hydraulic fracturing according to the NPV diagram was selected to achieve the optimum length. The best fracture half-length for AZ-X well is 1100 feet and for MNS-Y well is 900 feet.

According to reservoir simulations, hydraulic fracturing can significantly improve the recovery factor, as well as oil production rate. Therefore, we can use hydraulic fracturing operations as an effective method for improving oil recovery.

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