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SIMULATION AND OPTIMIZATION OF THE HYDRAULIC FRACTURING OPERATION IN A HEAVY OIL RESERVOIR IN SOUTHERN IRAN

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Abstract

Extraction of oil from some Iranian reservoirs due to high viscosity of their oil or reducing the formation permeability due to asphaltene precipitation or other problems is not satisfactory. Hydraulic fracturing method increases production in the viscous oil reservoirs that the production rate is low. So this is very important for some Iranian reservoirs that contain these characteristics. In this study, hydraulic fracturing method has been compositionally simulated in a heavy oil reservoir in southern Iran. In this study, the parameters of the fracture half length, the propagation direction of the cracks and the depth of fracturing have been considered in this oil reservoir. The aim of this study is to find the best scenario which has the highest recovery factor in this oil reservoir. For this purpose the parameters of the length, propagation direction and depth of fracturing have been optimized in this reservoir. Through this study the cumulative oil production has been evaluated with the compositional simulation for the next 10 years in this reservoir. Also at the end of this paper, increasing the final production of this oil reservoir caused by optimized hydraulic fracturing has been evaluated.

Keywords: Hydraulic fracturing, Compositional simulation, Recovery factor, Fracture length.

1. Introduction

Permeability of the reservoir rock is considered desirable when pores of the reservoir rock are connected to each other and also in case of easily flow into the wellbore. But in the case of low permeabilities, fluid is not easily able to move through the reservoir rock to the wellbore. In these cases, rock channels do not allow as they should to fluid flow into the wellbore and the well will not produce

Nomenclatures

API	Oil gravity, (API=141.5/$\gamma_{o,stc}$-131.5)
C_r	Rock compressibility, 1/atm
C_t	Total compressibility, 1/atm
D_x	Gridlock length in x direction, m
D_y	Gridlock length in y direction, m
D_z	Gridlock length in z direction, m
N_x	Number of gridblock in x direction
N_y	Number of gridblock in y direction
N_z	Number of gridblock in z direction
$P_{av,res}$	Average reservoir pressure, atm
P_b	Bubble point pressure, atm
$P_{i,aquifer}$	Initial aquifer pressure, atm
$PI_{aquifer}$	Aquifer productivity index, m^3/s/atm
S_{oi}	Initial oil saturation, %
$V_{i,aquifer}$	Initial volume of water in the aquifer, m^3

Greek Symbols

$\gamma_{o,stc}$	Oil specific gravity at standard condition

Abbreviations

FOPT	Field oil production totally
FPR	Field pressure rate

economically, because oil or gas is not produced to the extent necessary from the well. That's why we need to create fractures and artificial channels in the reservoir rocks. In fact, these channels which are created by hydraulic fracturing operation, can improve the power of the reservoir rock to lead the reservoir fluid in to the wellbore. Thus hydraulic fracturing is one of key technologies to enhance the productivity of oil and gas wells. Hydraulic fracturing is the process in which a viscous fluid is injected in to the formation under high pressure and with a relatively high flow rate so that a crack would be created and expanded. Hydraulic fracturing process of underground formations has been widely considered during the last few decades in various fields of engineering. In the oil and gas industry this technique is used to create large cracks with high hydraulic conductivity for increasing flow rate of oil and gas through the low permeable hydrocarbon reservoirs to the drilled wells. In the field of environmental engineering, this technique is an effective method in increasing the efficiency of the soil In-situ remediation methods [1].

Extraction of geothermal energy by creating hydraulic fracturing in the dry and hot rocks and use of fluid cycle are other uses of this process. This method is only reliable method for measuring residual stresses field that are widely used due to its simplicity. Other important applications of this technology include such items as: Underground disposal of waste and toxic fluids, stimulation of water wells to produce water and in mining industries as a backup system in large-scale excavation of ores [2].

Despite all the above applications that hydraulic fracturing comes to them as a useful method, in some cases is considered as a destructive and undesirable. For example in the field of dam construction, hydraulic fracturing can cause cracks in the core of the earth dams. Leaking and in some cases failure of earth dam are consequences of these cracks [3].

Decomposition of buried radioactive materials in the soil and saturated rock generates heat and thereby cause expanding both soil and water in the field of nuclear waste's land disposal. But this can lead to cracks in the soil because the water expansion coefficient has increased [4].

Also in designing of slurry injection process, hydraulic fractures that may occur during penetrating or consolidation slurry injection can significantly decrease the ability of slurry for sealing or improving the resistance [5].

Therefore needing for understanding the mechanisms of hydraulic fractures initiation and propagation in the various field of engineering has made that the analysis of this phenomenon and trying for achieving a suitable model to its simulating, strongly be considered. However, the importance of hydraulic fracturing process in oil and gas industry to achieve the hydrocarbon reserves or increase their production is the main motive to create such models.

2. Hydraulic Fracturing in Oil and Gas Industries

The first application of hydraulic fracturing for increasing the extraction of oil and gas from the underground reservoirs was in Hugoton field in western Kansas. In 1947 hydraulic fracturing conducted to comparing with acidizing technology on a gas well in this region by the Pan American Petroleum Corporation. At that time no one imagined that this will be the beginning of a great movement and new technologies for well stimulation. Perhaps the most optimistic observers didn't think that before 1981 about one million hydraulic fracturing operations performed worldwide. After that and until the mid-1960s, hydraulic fracturing became dominant method for stimulation of oil and gas wells in this area and the other areas [6].

Only in the United State about 40% of oil wells and 70% of gas wells were completed by hydraulic fracturing since 1993 to2005. Moreover in Algeria about 20 hydraulic fracturing operations in Hessy M. field since 1970 to 1980 and additionally about 150 wells were completed by hydraulic fracturing until 2005. Producing countries in the Middle East especially Iran's competitors have greatly increase investments in hydraulic fracturing technology since 2000 [7]. Now in most producing countries in the Middle East hydraulic fracturing is used for well completion in most oil and gas wells. Unfortunately in our country hydraulic fracturing has not seriously considered except in a few cases. Hydraulic fracturing is a process of fluid injection into the well and makes a tensile stress in formation which is exposed to the fluid pressure such that leads to local stresses in formation in order to overcome the tensile strength. This creates fractures in formation which start from the wellbore and can propagate until fluid is injected continuously with a high rate. Propant (such as sand and ceramic balls) is also injected with the fluid so that during stopping of fluid pumping, created fractures remain as a permeable path for fluid flowing into the wellbore. In hydraulic fracturing should enough pressure apply for beginning of formation failure or breaking and also exposed pressure should continue to allow the fractures grow and spread. Naturally fracture injection process needs more pressure than fracture expansion stage. Generally there are two reasons for applying hydraulic fracturing in wells: 1) Increasing the productivity Index (PI), 2) Improving ultimate recovery factor.

3. Designing and Modelling of Hydraulic Fracturing

So far extensive efforts have been done to provide models for designing hydraulic fracturing especially in recent decades. Most of these models have had drawbacks minimum in three directions that include:

a) Assumptions that computational models have been proposed on base of them are general.

b) Complicated programming.

c) The instability in input and output indexes especially in comparison to the actual operating conditions.

However some models have good quality but this good quality is only seen in limited areas. One of the simplest models that are two-dimensional (2D) is the KGD model that considers the fracture width as a function of length. Another simplest model that is tow-dimensional (2D) is the PKN model which considers fracture width as a function of fracture height. Due to the length and height of the fracture expand during operation, accepting the being constant fracture height was not justified. So Cleary proposed a new Three-dimensional pseudo hydraulic fracturing. In the model proposed by Cleary fracture width has been considered as a function of the smaller dimension (length or height) with considering the fracture length and height changes during operation. [8, 9] Therefore in this study the results of hydraulic fracturing modeling with pseudo 3D model are base to select the optimal values for the considered parameters.

Data required should be carefully collected for studying the possibility of performing hydraulic fracturing on selected wells. These data are generally divided into five categories:

A) Well static data, B) Well fluid data, C) Formation data, D) The reservoir parameters, E) PVT data.

4. Investigating of Hydraulic Fracturing in Oil Reservoir "Z" in Southern 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.

4.1. Studied field characteristics

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. (Table 2) This is a newly explored oil field and now is in a stage of development.

Studied field is in under saturation conditions and there is no gas cap in studied reservoir. Its reservoir rock is oil wet. Studied field has 16 oil layers with thickness of totally 196 m or 643 feet. Three-dimensional structure of "Z" oil reservoir with 16 oil layers has presented in Fig. 1.

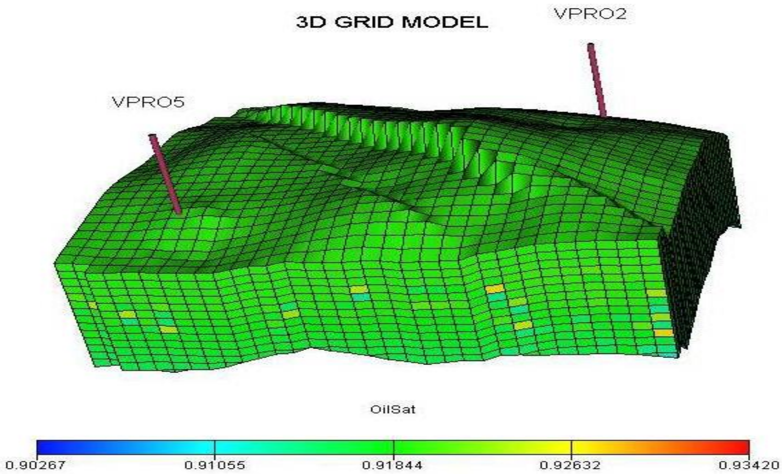

Fig. 1. Three-dimensional structure of "Z" oil reservoir in southern Iran with two producing fractured wells.

The average pressure of studied reservoir is about 240.5 atm (3535 psia). The datum depth of calculations is about 7100 feet in this reservoir. Oil-Water contact in this reservoir has estimated at 2164.7 m (7453.1 ft) and Gas-Oil contact is estimated about 526 m (1725 ft). The datum depth for aquifer calculations has estimated at 2286.6 m (7500 ft) in this reservoir. Aquifer characteristics are presented in Table 1. The calculations of water influx through the aquifer to the oil reservoir and aquifer productivity index have been done by Fetkovich's aquifer model in this study (Fetkovich, 1971) [10].

Table 1. Aquifer properties in "Z" oil reservoir.

Property	Value	Unit
$P_{i,aquifer}$	77763	atm
$V_{i,aquifer}$	0.32E+09	m^3
C_t	95.55E-006	atm^{-1}
$PI_{aquifer}$	0.271	$m^3s^{-1}atm^{-1}$

Figure 2 shows distribution of water saturation in the three-dimensional structure of studied reservoir. Also how and direction to contact of aquifer to the reservoir is shown in Fig. 2.

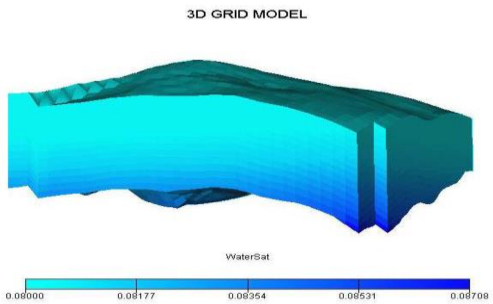

Fig. 2. Distribution of water saturation in three-dimensional structure of "z" oil reservoir in southern Iran.

4.2. A summary of the geology and fluid properties of the studied field

As mentioned, studied reservoir is a single-porosity sand stone reservoir. Its oil is a relatively heavy with API grade of 25. GOR and oil formation volume factor (FVF) have estimated about 700 SCF/STB and 1.4 Rbbl/STB, respectively. The rock compressibility is about $41.16*10^{-6}$ atm^{-1}. The average horizontal and vertical permeability have estimated about 154.55 md and 2.1 md, respectively. Also the average reservoir temperature and pressure have estimated about $60^{\circ}C$ and 77763 atm, respectively in this reservoir. A summary of the geology and fluid properties of the studied field is presented in Table 2.

Table 2. Fluid general characteristics of the studied field.

Properties	Value	Properties	Value
API	25	**S_{oi}, %**	79
Total thickness, m	195.7	**Oil Viscosity, cp**	0.68
GOR, SCF/STB	700	**Gas Viscosity, cp**	0.021
C_r, atm^{-1}	41.1×10^{-6}	**T_R, $^{\circ}C$**	60
Average Porosity , %	12.5	**P_b, atm**	29326.5
B_o, Rbbl/STB	1.4	**P_R, atm**	77763
$K_{x, av}$, md	154.55	**Oil in Place, m^3**	0.51×10^8
$K_{z, av}$, md	2.1		

4.3. Characteristics of the field static model

A summary of characteristics of the field static model is presented in Table 3.

Table 3. Characteristics of the field static model.

Properties	Value	Properties	Value
N_x	32	**D_x, m**	108.93
N_y	32	**Dy, m**	109.94
N_z	16	**D_z, m**	0.1-6.1
Number of oil layers	16	**Number of cells**	16384

4.4. PVT data of the studied field

In this study LBC correlation method has been used for calculation of oil viscosity. LBC correlation method is used in a large number of compositional simulations.

Lohrenz et al. (1964) supposed a method for calculating the hydrocarbon mixtures and reservoir fluids [11]. Their method was similar to Jossi et al. (1962) for pure fluids. LBC correlation method is a polynomial of degree 6 at residual density. This makes increasing the sensitivity of viscosity than other parameters changes.

$$[(\mu - \mu_o)\xi + 10^{-4}]^{\frac{1}{4}} = d_0 + d_1\rho_r + d_2\rho_r^2 + d_3\rho_r^3 + d_4\rho_r^4 \tag{1}$$

where μ_o is the dilute gas viscosity, ξ, residual viscosity and ρ_r is the fluid residual density that defined as follows:

$$\rho_r = \frac{\rho}{\rho_c} \tag{2}$$

where ρ_c is the fluid critical density. Coefficients d_i in above equation is as follows:

d_0= 0.1023 d_1=0.023364 d_2=0.058533 d_3=-0.040758 d_4=0.0093324.

Lohrenz et al. (1964) introduced the following equations for calculating viscosity of dilute gas and residual viscosity:

$$\zeta = \frac{\left(\sum_{i=1}^{n} x_i T_{c,i}\right)^{1/6}}{\left(\sum_{i=1}^{n} x_i M_{w,i}\right)^{1/2}\left(\sum_{i=1}^{n} x_i P_{c,i}\right)^{2/3}} \tag{3}$$

$$\mu_0 = \frac{\sum_{i=1}^{n} x_i \mu_{0,i}\sqrt{M_{w,i}}}{\sum_{i=1}^{n} x_i\sqrt{M_{w,i}}} \tag{4}$$

where T_{ci} is the critical temperature, P_{ci}, critical pressure, M_{wi}, molecular weight and i is the mole fraction of component “i” in the mixture. A PVT simulator has been used in this study to simulate the behaviour of reservoir fluid at different temperatures and pressures. Also the SRK Three-parameter equation of state (EOS) has been used for the regression of both experimental and software data and coefficients of EOS have been altered in a way that consistent with experimental data and able to predict the behaviour of reservoir fluid at different pressure and temperature. In this study first it has been tried to obtain a good match with no change in composition of the considered sample, but because the result was not perfect, so C_{7+} was divided to two groups of C_{7+} and C_{14+}. Then for better result C_{14+} was divided to two groups of C_{14+} and C_{25+}. This grouping is presented in Table 4. The splitting method by solving method of Whitson and EOS of Lee-Kessler has been used. The result of matching the EOS parameters with the available laboratory data of reservoir fluidby using PVT simulator are presented in Figs. 3 to 5. The Adjustment of oil formation volume factor (B_o) with the available laboratory data of reservoir fluid by using PVT simulator are presented in Fig. 3. Matching of dissolved gas in the oil (R_s) and gas volumetric coefficient are presented in Figs. 4 and 5, respectively.

Table 4. Reservoir fluid composition after grouping process.

Component	Mole fraction	Component	Mole fraction
C_1	6.2914	C_6	2.5673
C_2	2.0953	C_7^+	42.403
C_3	2.1477	C_{14}^+	28.514
IC_4	0.72337	C_{25}^+	9.3076
NC_4	1.9261	H_2S	0.5706
IC_5	1.218	CO_2	0.63909
NC_5	1.5962		

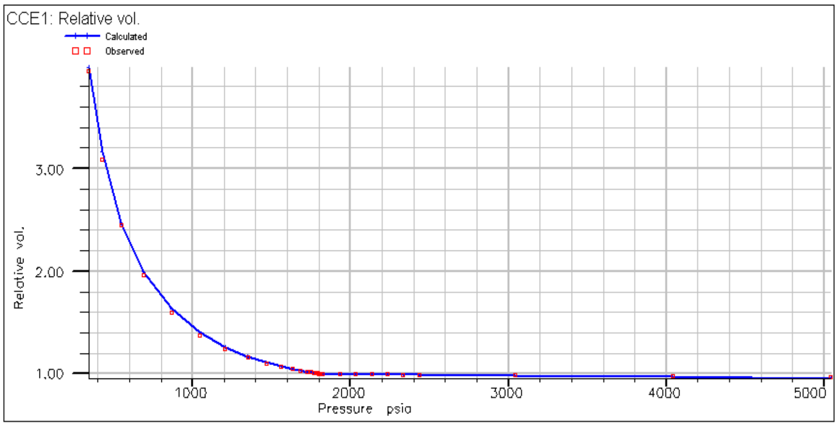

Fig. 3. The adjustment of relative volume as a function of pressure.

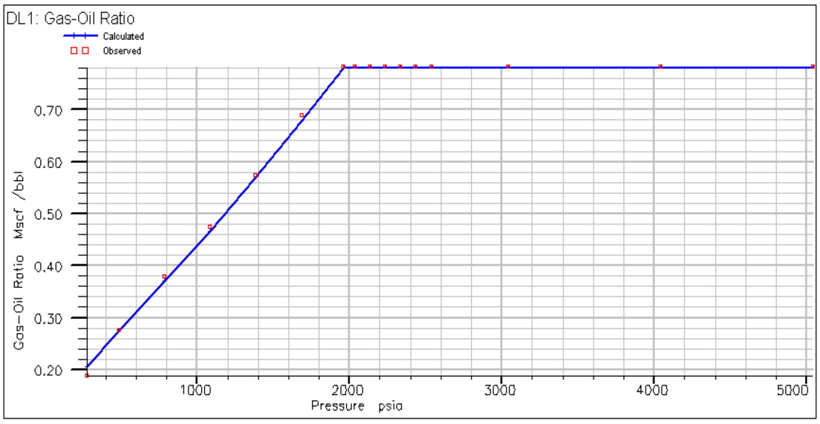

Fig. 4. Matching of dissolved gas in the oil as a function of pressure.

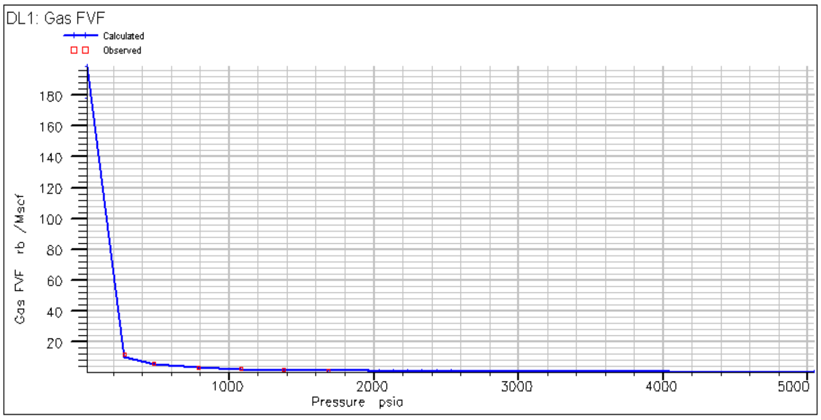

Fig. 5. Matching of gas volumetric coefficient as a function of pressure.

5. Simulation and Optimization of Hydraulic Fracturing by Analyzing the Different Scenarios in the "Z" Oil Field in the Southern Iran.

5.1. Scenario 1: Evaluating the effect of hydraulic fracture half length on increasing productivity index in oil wells in "Z" oil field

The aim of the investigation of this scenario is analysis of the impact of fracture half-length on increasing the cumulative oil production from the studied reservoir in a standard range of hydraulic fracturing operation (about 304.9 m or 1000 ft) [12] . In this study the purpose of the hydraulic fracturing length is the created fracture along one side of the well which is able to fluid flow or half of the created fracture length on both sides of the well which is able to fluid flow.

5.1.1. Scenario 1-A:

In scenario 1-A the fracture length has been equal to summation of 1.5gridblock length in X direction (about 163.1 m or 535 ft) at the static basic model.

5.1.2. Scenario 1-B:

In this scenario the fracture length has been equal to summation of the total length of two gridblock and half a gridblock length in X direction (about 272 m or 892 ft) at the static basic model.

5.1.3. Scenario 1-C:

In this scenario fracture length parameter has increased again and this time has considered about 380.8 m(1249 ft). In other words the hydraulic fracturing length has considered equal to summation of 3 gridblock length and half length of a gridblock in "X" direction in basic static model of studied reservoir.

The results of simulating the effect of fracture length on the cumulative oil production in reservoir "Z" are presented in Fig. 6. Also simulating the effect of fracture length on the pressure drop in "Z" reservoir is presented in Fig. 7. Also the results of simulating scenario 1 are presented in Table 5.

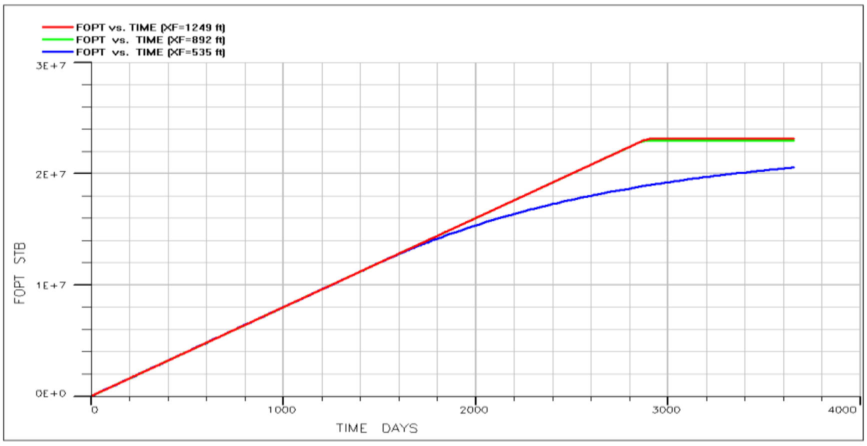

Fig. 6. Considering the effect of fracture length on the cumulative oil production in reservoir "Z".

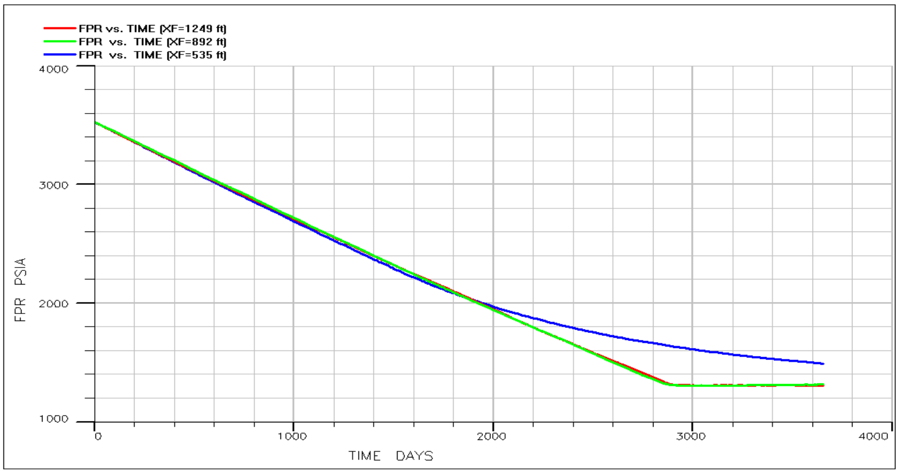

Fig. 7. Considering the effect of fracture length on the pressure drop in reservoir "Z".

Table 5. Scenario 1.

Scenario	FOPT (m^3)	FPR (atm)
Scenario 1.A	$3.3*10^6$	101.45
Scenario 1.B	$3.65*10^6$	89.46
Scenario 1.C	$3.68*10^6$	88.75

By comparing the scenarios related to the fracture length we concluded that increasing the hydraulic fracturing length has increased cumulative oil production in reservoir "Z".

Scenario 1-C has been produced 0.48 million m^3 (3 million bbl) more than scenario 1-A after 10 years. By comparing scenarios 1-C and 1-B we concluded that increasing cumulative production with increasing fracture length was about 15.91 m^3 (100 bbl) after 10 years. So scenario 1-B seems to be the most economical scenario related to the fracture length optimization. The reason of the significant different between the final production between scenario 1-B and 1-A is increasing the well effective radius due to decreasing skin factor and increasing the permeability around the well. Because in scenario 1-B the hydraulic fracture length has been considered 2 times more than scenario 1-A. It has given this possibility to the well in scenario 1-B with this increasing so that it can produce through more reservoir drainage radius. Also one of the reasons that production has not significant increased in scenario 1-C with increasing fracture length to 380.8 m(1249 ft), was quick pressure drop in the reservoir. As seen in Fig. 7, the slopes of the pressure drop are approximately equal in scenario 1-B and 1-C. This has made the pressure to reach about 88.43 atm (1300 psia) after about 8 years. This has made the increasing in production to trace amount of 15.9 thousand m^3(100 thousand bbl). By comparing the costs of increasing the fracture length in hydraulic fracturing operation scenario 1-B is proposed as the optimal scenario.

5.2. Scenario 2: Considering the effect of hydraulic fracturing location in hydraulic fractured wells on the ultimate recovery factor in reservoir "Z".

The goal of defining this scenario is evaluating the productivity of different oil layers after performing the hydraulic fracturing. In this scenario different layers of studied reservoir have been selected for hydraulic fracturing propagation. Then layers that have had the greatest ultimate recovery factor are recognized as selective layers for hydraulic fracturing according to the predicted productivity results for different layers. It should be noted that flow rate has been considered equal for all scenarios in this section.

5.2.1. Scenario 2-A:

In this scenario the location of fracturing has been selected in layers of sixth, seventh and eighth. For defining this scenario first studied wells should be completed in the layers of sixth to eighth. Then hydraulic fractures be defined by extending in the horizontal direction in these layers.

5.2.2. Scenario 2-B:

In this scenario the location of hydraulic fracturing creation has been selected in layers of eighth, ninth and tenth. To define this scenario first production well has been completed the eighth to tenth layers. Then propagation of hydraulic fractures has been defined in the horizontal direction in these layers for producing wells in the reservoir "Z".

The results of simulating the effect of fracture location on the cumulative oil production in reservoir "Z" are presented in Fig. 8. Also simulating the effect of fracture length on the pressure drop in "Z" reservoir is presented in Fig. 9.

With considering the two scenarios 2-A and 2-B for reservoir "Z" we concluded that scenario 2-A (The scenario of hydraulic fracturing creation in layers sixth, seventh and eighth) had the higher cumulative oil production. The main reason for the difference in the cumulative hydrocarbon recovery in layers sixth to eighth than the deeper layers is the higher permeability and NTG in these layers. According to Fig. 8 we can find that for the first 4 years there is no much difference between the two scenarios 2-A and 2-B according to the cumulative oil production. The production rate has been surpassed in scenario 2-A than scenario 2-B after 4 years. Also the results of simulating scenario 2 are presented in Table 6.

Table 6. Scenario 2.

Scenario	FOPT (m^3)	FPR (atm)
Scenario 2.A	3.6×10^6	89.4
Scenario 2.B	3.3×10^6	100.3

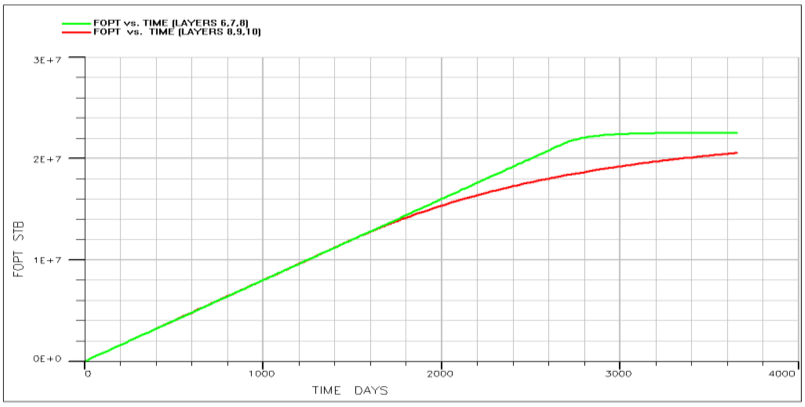

Fig. 8. Considering the effect of location of created hydraulic fractures on the cumulative oil production in the studied reservoir

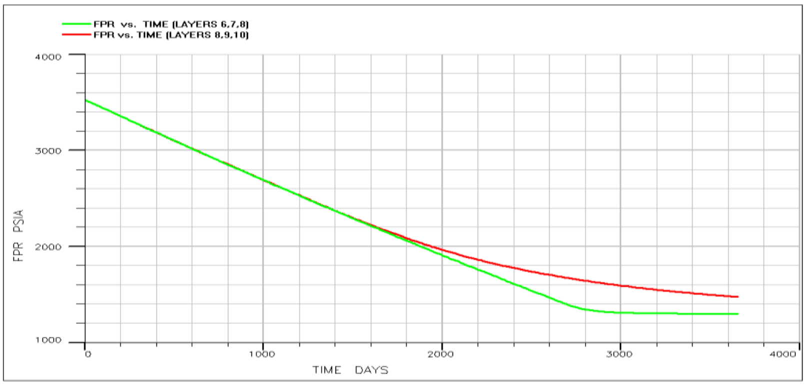

Fig. 9. Considering the effect of hydraulic fractures location on the pressure drop in the studied reservoir.

5.3. Scenario 3: Comparing the advantages of the production from hydraulic fractured wells than non hydraulic fractured wells:

The goal of this considering is to measure the cumulative increased oil production as result of the hydraulic fracturing operation than producing with non hydraulic fractured wells in reservoir “Z”. For this the two scenarios of production without well stimulation and production with hydraulic fracturing has been defined. Notably that production conditions has been considered the same in both scenarios.

5.3.1. Scenario 3-A:

In this scenario wells No. 2 and 5 have been completed in the sixth to eight layers. This scenario is called “doing noting”, because after completing wells in this scenario no stimulation operations such as hydraulic fracturing are defined for these wells. In fact the wells produce with reservoir natural depletion energy and without hydraulic fracturing. In this scenario the production from the reservoir “Z” has predicted for the next 10 years.

5.3.2. Scenario 3-B:

In this scenario wells No. 2 and 5 in this reservoir have been completed with hydraulic fracturing in horizontal direction ("X" direction). Production from the reservoir "Z" has predicted for the 10 next years with open and stabilized hydraulic fractures.

The results of comparing the advantages of the production from hydraulic fractured wells than non hydraulic fractured wells are presented in Fig. 10. Also the simulating the pressure drop with and without hydraulic fracturing in "Z" Reservoir is presented in Fig. 11. Also the results of simulating scenario 3 are presented in Table 7.

Table 7. Scenario 3.

Scenario	FOPT (m^3)	FPR (atm)
Scenario 2.A	3.27×10^6	101.45
Scenario 2.B	3.7×10^6	88.75

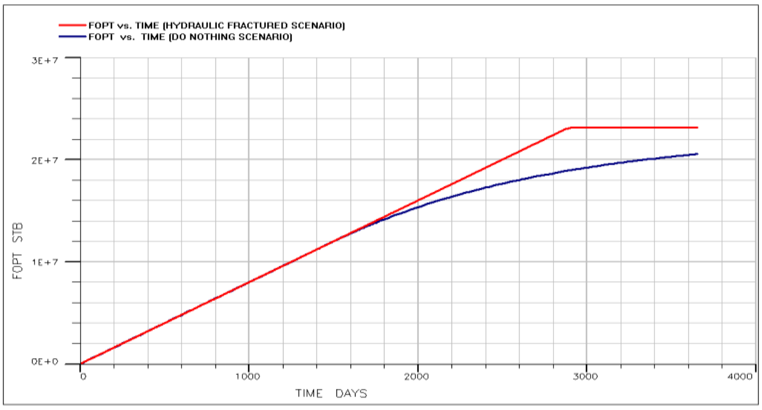

Fig. 10. Considering the production with and without hydraulic fracturing in "Z" reservoir.

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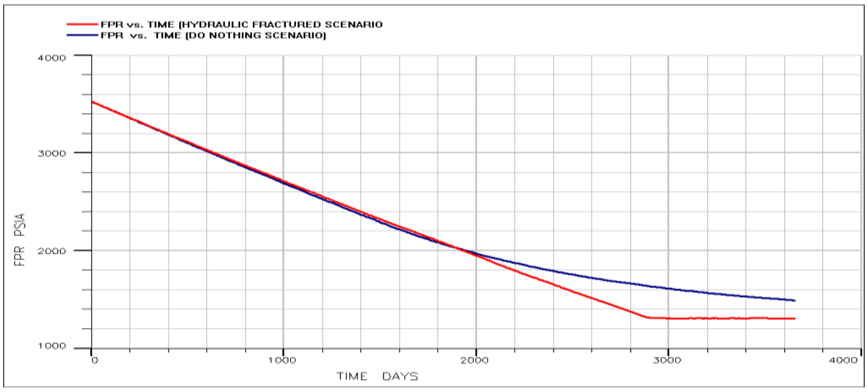

Fig. 11. Considering the pressure drop with and without hydraulic fracturing in "Z" reservoir.

6. Conclusions and Recommendations

Some concluding observations from the investigation are given below:

- By considering the different hydraulic fracture length scenarios in reservoir "Z" we concluded that the cumulative oil production is increased by increasing the fracture length.
- In the studied reservoir by increasing the fracture length to about 892 ft cumulative oil production rises with steep gradient but in higher lengths this slope is decreased.
- In this study the most economical scenario of fracture length is determined about 890 ft for the reservoir "Z".
- By considering the fracture creation location's scenarios for reservoir "Z" we concluded that the intermediate layers (sixth, seventh and eighth layers) are the best layers to the hydraulic fracturing operation.
- In this study after optimization of length, direction and location parameters for creation of hydraulic fractures in the reservoir "Z" an improving ultimate recovery about 0.48 million m^3 (3 millionbbl) has predicted for the next 10 years.

By considering the pressure drop curves in reservoir "Z" for increasing the fracture length scenarios, it can be concluded that by increasing the fracture length more than optimized value of 271.4 m (890 ft), reservoir pressure drops following 136 atm (2000 psia) after 5 years production. Thus production from the reservoir by reservoir natural depletion intensity decreases. Therefore recommended to be use enhance oil recovery methods (EOR) to stabilized the reservoir pressure such as miscible gas injection method in addition to hydraulic fracturing [13].

Science the reservoir "Z" is a heavy oil reservoir, in addition to the hydraulic fracturing thermal EOR methods [14] seem very useful for increasing ultimate recovery of this reservoir.

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