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Research Article

Designing of Hydraulic Fracture Job and Performance Analysis of Extremely Low Permeability Oil Reservoirs

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Abstract: In case of extremely low permeability reservoirs, stimulation techniques are mostly required to enhance the production of wells. During these times of energy crises unconventional reservoirs have got significant importance. In such situations, proper designing and execution of hydraulic fracture job (HFJ) is required to produce wells at attractive production rates. By using this technique, wells can produce more, resulting in higher production from the reservoirs. In this paper, a hydraulic fracture job has been designed and its impact on oil production has been estimated by performing pre- and post-fracture reservoir performance calculations, using developed SMART software. While conducting this study, effect of varying fracture half-length in extremely low permeability oil reservoirs has been investigated and the impact of the same fracture half-length in varying permeability reservoirs has also been analyzed. The results of this study indicate that propagated fractures increases flow rate of wells. It has also been observed that initially the fracture half-length impacts the production appreciably; however, with further increase, it does not affect the production rate to the same magnitude.

Keywords: Low permeability reservoirs, hydraulic fracture job, reservoir performance, HFJ design

1. INTRODUCTION

It is nearly impossible to produce low permeability reservoirs at economical rates, based on their natural potential. In some cases, tight formations (having natural fractures) and naturally fractured reservoirs can also have low productivity, if the existing fractures are not extended upto the wellbore [1, 2].

Therefore, in such cases hydraulic fracture job is required. In HFJ, fracturing fluid is injected at high pressures, resulting into creating fractures into the formation of varying extensions. Later, when the injection of fracturing fluid stops, the added proppants remain in the fracture, keeping the generated fractures open [3-5]. Thus resulting into increased production rates from a well and in broader sense for a reservoir [4, 6, 7]. The significance of HFJ to increase the well productivity has been demonstrated by a number of field case studies [3, 7, 8]. After implementing hydraulic fracture job, overall impact of results on reservoir production can be analyzed by performing post-frac analysis, in which simulation studies can also be included [6, 9-11].

2. HYDRAULIC FRACTURE JOB DESIGNING AND RESERVOIR PERFORMANCE ANALYSIS

Consider a fracture system in a reservoir as shown in Fig. 1. For designing and modeling of HFJ in such reservoirs, a number of models owing to different technical limitations are available in literature. Namely, PKN, KGD and pseudo 3-D models are some of them [5, 12-14]. KGD model is used, when the required fracture height is greater than fracture half-length, while pseudo 3-D models require information pertaining to overlying and underlying formations (with reference to formation, in which HFJ needs to be executed) [5, 12]. In this study PKN model has been used, in which fracture half-length is kept greater than fracture height. Mathematically [5]:

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$$\overline{w} = 0.3\left\{\frac{q_i\mu(1-\upsilon)x_f}{G}\right\}^{\frac{1}{4}}\frac{\pi}{4}\gamma \quad (1)$$

After calculating average width of fracture, equivalent skin factor and other major steps involved in calculating the successfulness of hydraulic fracture job are briefly described below, however detailed discussion can be found in literature [4-6, 14-16]. Equivalent skin factor can be calculated by using the following equation [13].

$$s_f = \frac{1.65-0.328ln(F_{CD})+0.116[ln(F_{CD})]^2}{1+0.180ln(F_{CD})+0.064[[ln(F_{CD})]^2+0.05[ln(F_{CD})]^3]} - ln\left(\frac{x_f}{r_w}\right) \quad (2)$$

Where,

$$F_{CD} = \frac{k_f w}{k x_f} \quad (3)$$

The folds of increase in productivity index as a result of HFJ can be calculated by using the following equation [12].

$$\frac{J}{J_o} = \frac{ln\left(\frac{r_e}{r_w}\right)}{ln\left(\frac{r_e}{r_w}\right)+s_f} \quad (4)$$

After that pre- and post-frac reservoir performance can be analyzed by using equations, which are selected based on reservoir pressure. If $P_R \geq P_b$, then straight line inflow performance relationship (IPR) is used for predicting reservoir performance, which can be written as [13]:

$$q = J(P_R - P_{wf}) \quad (5)$$

and if the reservoir pressure is below bubble point or declines below the bubble point pressure, then vogel equation can be used [13].

$$q = q_{max}\left[1 - 0.2\left(\frac{P_{wf}}{P_R}\right) - 0.8\left(\frac{P_{wf}}{P_R}\right)^2\right] \quad (6)$$

or,

$$q = q_b + \frac{JP_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf}}{P_b}\right) - 0.8\left(\frac{P_{wf}}{P_b}\right)^2\right]$$

For analyzing reservoir performance before and after HFJ, same set of equations are used, while incorporating pre- and post- value of productivity index.

3. IN-HOUSE DEVELOPED SMART SOFTWARE FOR HFJ DESIGN AND RESERVOIR PERFORMANCE ANALYSIS

To design HFJ and to predict reservoir performance, a SMART software has been developed. This software also gives an option to estimate and perform sensitivity analysis. The developed algorithm can be explained with the help of flow chart as shown in Fig. 2.

4. CASE STUDIES

Hydraulic fracture job is designed and later reservoir performance has been predicted by using above discussed methodology for extremely low permeability oil reservoir having a depth of 8000 ft. The permeability of a reservoir was varied from 0.085 to 0.9 md and fracture half-lengths were 100, 150 and 200 ft. Further details of reservoir and proppant properties are given in Table 1.

Table 1. Input data used in SMART software for HFJ design and reservoir performance analysis**.**

Parameter	**Value**
Depth	8000 ft
Diameter of tubing (ID)	2.259 in
Pipe relative roughness	0.0006
Minimum horizontal stress	6300psi
Maximum horizontal stress	8865 psi
Tensile strength	1095 psi
Formation pressure	6900 psi
Poisson's ratio	0.25
Shear strain	0.75
Wellbore radius	0.5 ft
Proppant permeability	250,000 md

The calculations have been performed, firstly by keeping the reservoir permeability constant and varying the fracture half-length (Case 1) and later the effect of constant fracture half-length has been investigated by varying the formation permeability (Case 2). The obtained results are shown in Fig. 3 to 5 for Case 1 and from Fig. 6 to 8 for Case 2.

Fig. 3 to 5 show that with the increase in fracture half-length, i.e, as the penetration of the fracture within the reservoir increases, oil production also increases for the same wellbore flowing pressure. With the increase in fracture half-length, the production rate increases, but that increase in rate is not proportional with the increase in x_f, or in other words with the equal increase in fracture

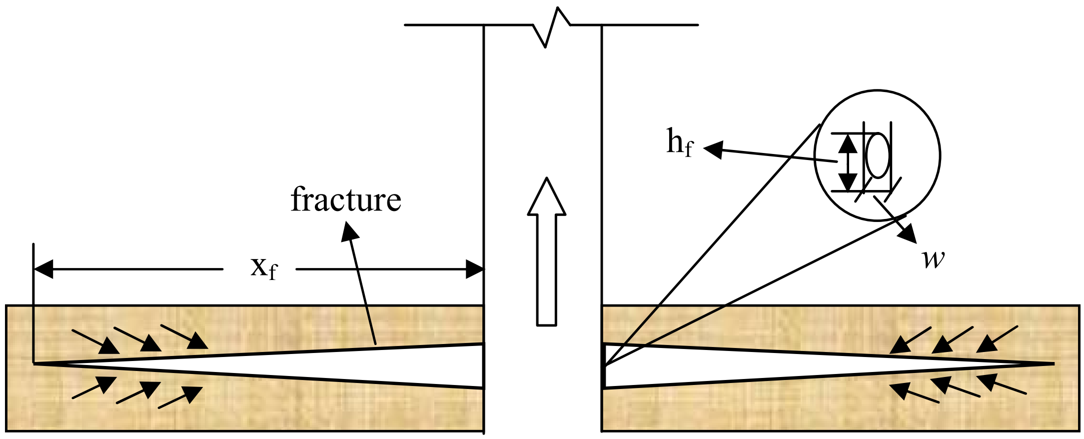

Fig. 1. Schematic diagram of propagated fracture and associated parameters.

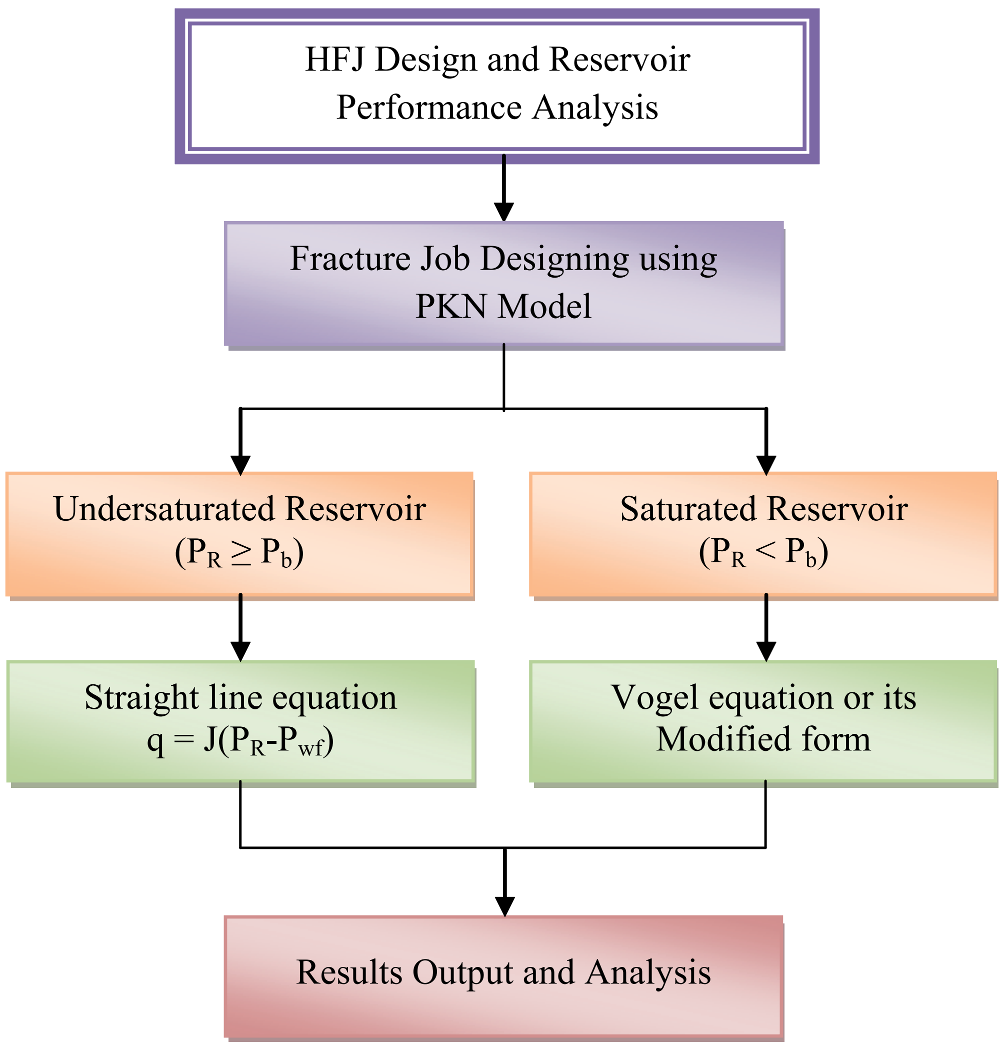

Fig. 2. Algorithm for developed SMART software.

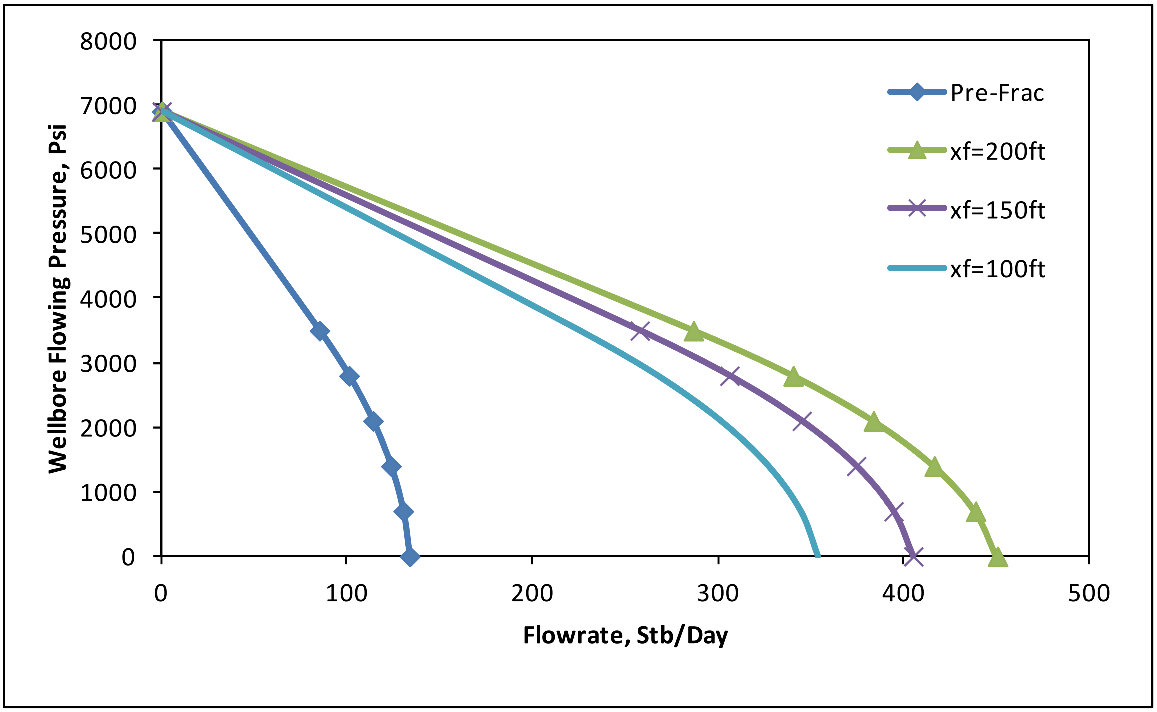

Fig. 3. Pre- and post-frac reservoir performance at k = 0.085 md and varying x_f.

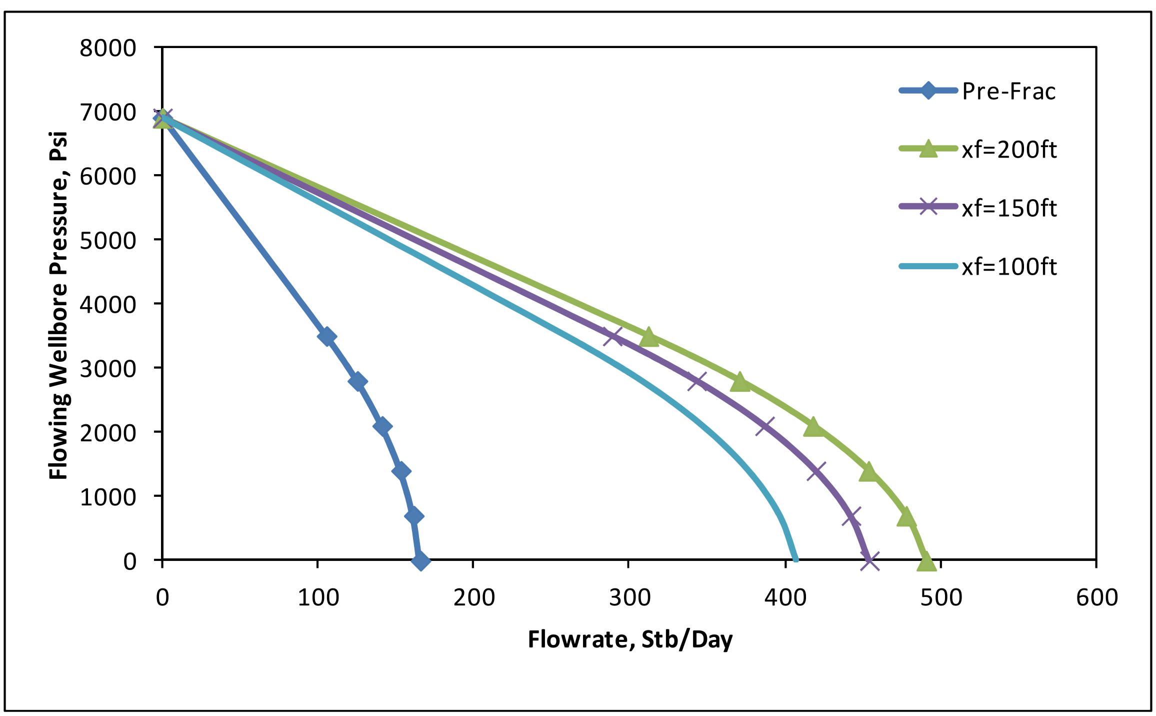

Fig. 4. Pre- and post-frac reservoir performance for reservoir permeability of 0.5 md.

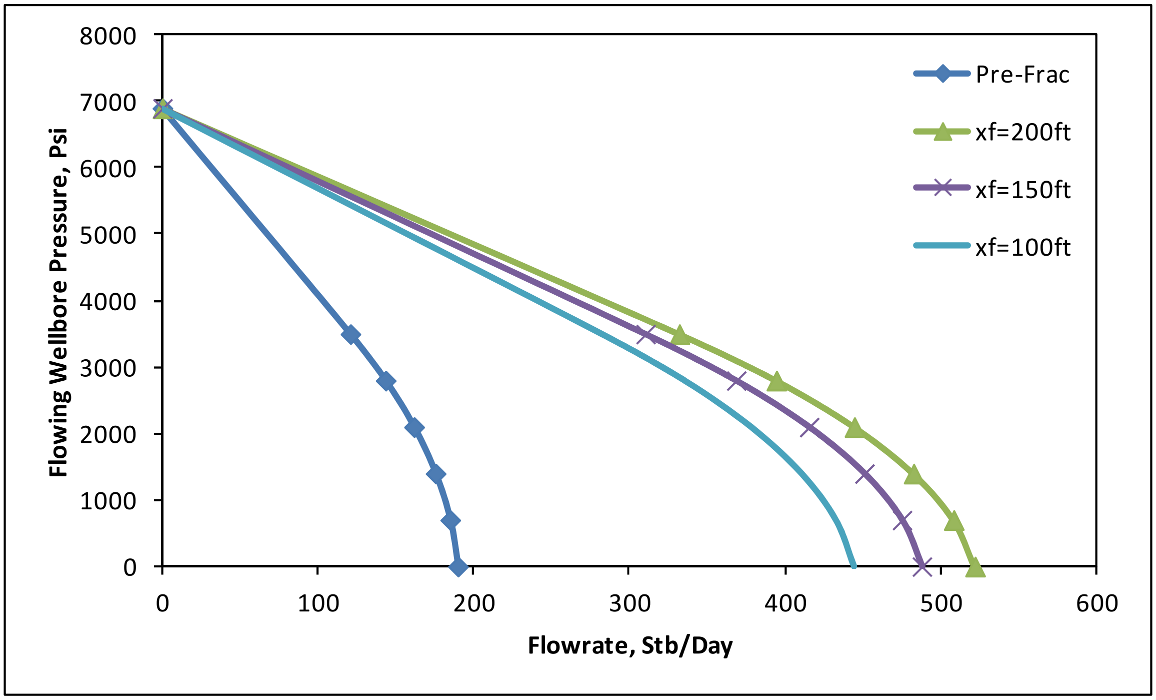

Fig. 5. Pre- and post-frac reservoir performance for k = 0.9 md.

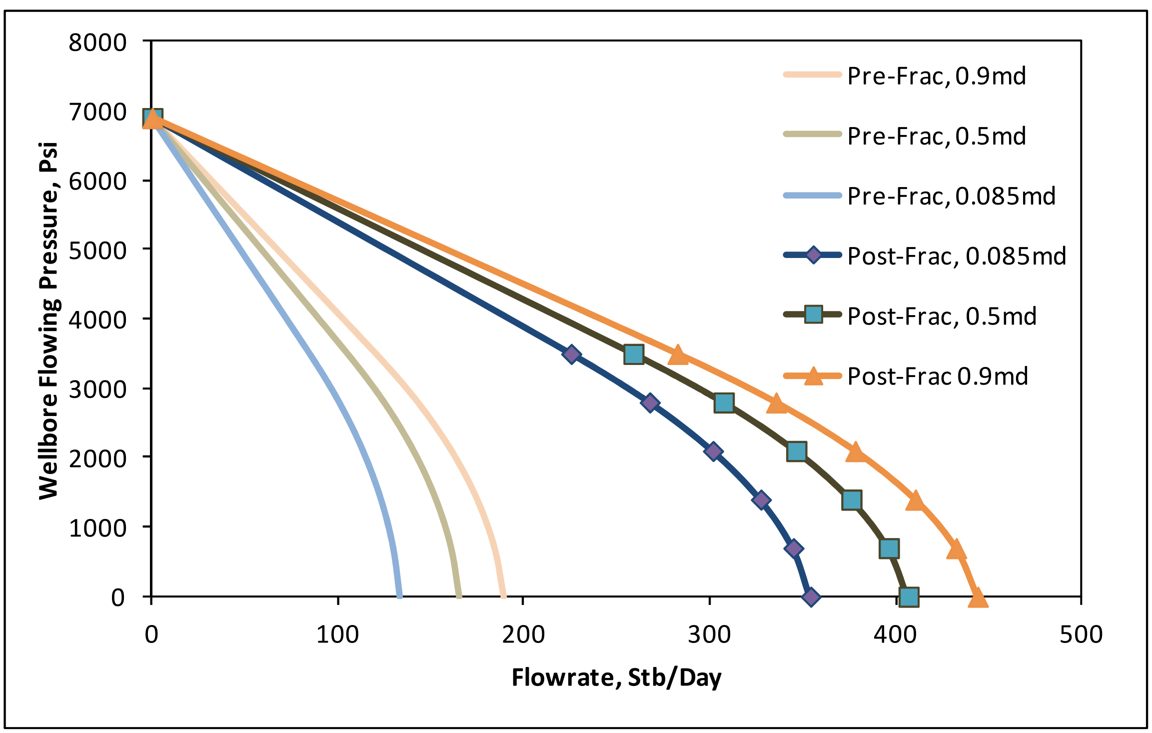

Fig. 6. Reservoir performance prediction for varying permeability and constant x_f (100 ft).

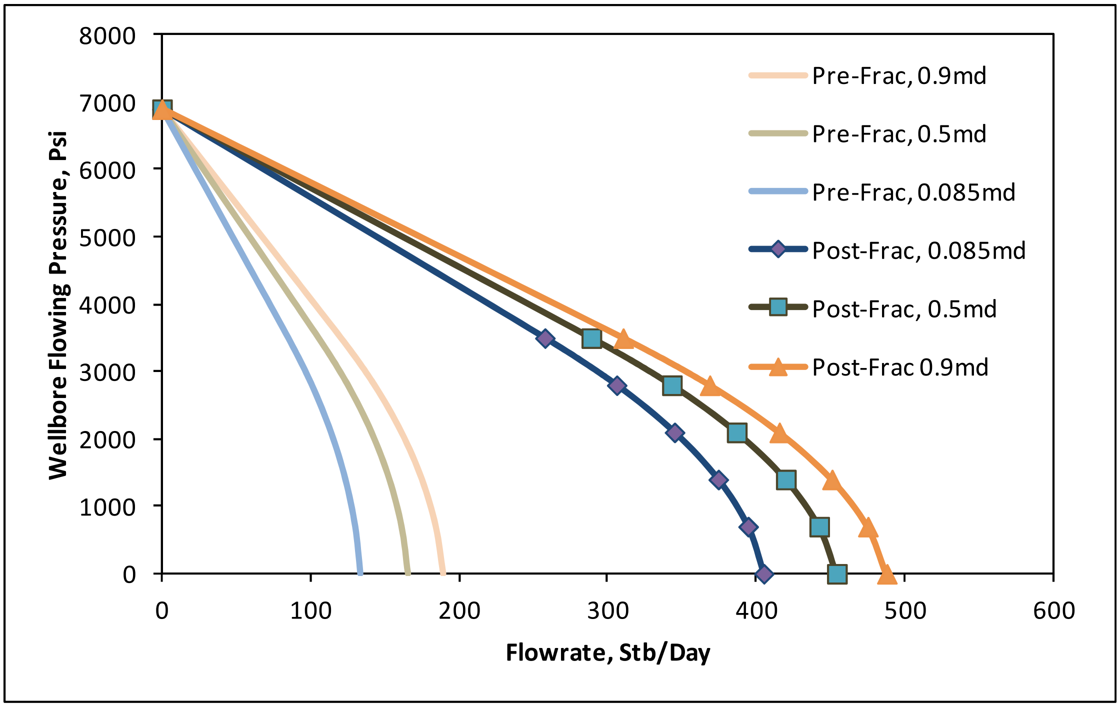

Fig. 7. Reservoir performance prediction for varying permeability and x_f =150 ft.

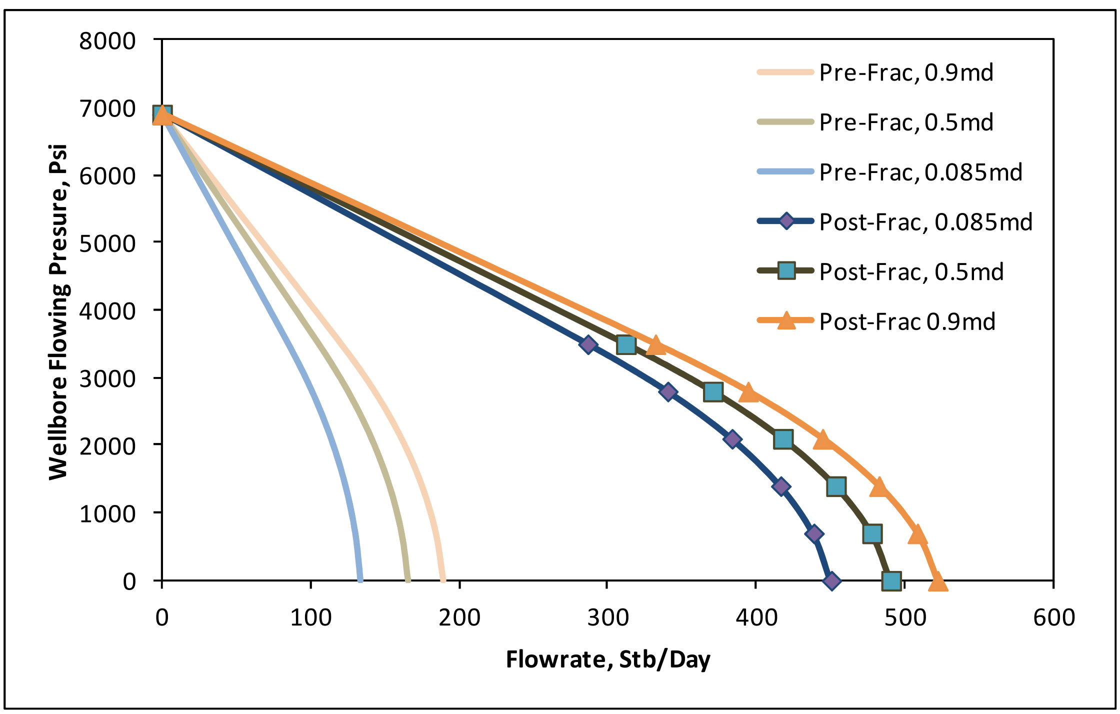

Fig. 8. Reservoir performance prediction for varying permeability and x_f =200 ft.

half-length, the increase in production rate does not increase with the same ratio.

In this study it has also been analyzed that how the increase in reservoir permeability can decrease the required fracture half-length, while maintaining the same flow rate (Case 2), as shown in Fig. 6 to 8. The pre-frac analysis remains the same and the results of post-frac analysis changes with the change in reservoir permeability. These figures show that as the permeability of reservoir increases from 0.085 to 0.9 md, the required fracture half-length to produce oil, approximately at the same rate, decreases. For, example, x_f = 200 ft is required when permeability is 0.5 md, but x_f = 150 is required, when permeability is increased to 0.9 md, to achieve a production rate of 488 stb/day.

The results are summarized in Table 2 and 3. Table 2 gives a comparison of pre- and post-frac productivity index values. The table shows that after hydraulic fracturing the productivity index or reservoir constant has been increased. While, Table 3 shows that how much folds of increase in production is obtained as a result of creating fractures of varying half-lengths in a same permeability reservoir/formation. The table shows that with the increase in fracture half-length, flowrate becomes more than double as compared to pre-frac results. It can also be depicted that in lowest permeability formation, the impact of fracture half-length is more significant as compared to higher permeability formations.

Table 2. Effect of fracture half length on productivity index.

Formation Permeability (md)	Fracture Half-Length, x_f (feet)	Productivity Index, J (Stb/Day/Psi)	
		Pre-Frac	Post-Frac
0.085	100	0.02	0.07
	150		0.08
	200		0.084
0.5	100	0.03	0.08
	150		0.085
	200		0.09
0.9	100	0.04	0.08
	150		0.09
	200		0.1

Table 3. Effect of fracture half length on production rate in terms of folds of increase.

Permeability (md)	Fracture Half-Length, x_f (feet)	Dimensionless Fracture Conductivity, F_{cd}	Folds of Increase
0.085	100	59.583	2.65
	150	44.028	3.03
	200	35.417	3.37
0.5	100	11.917	2.46
	150	8.806	2.74
	200	7.083	2.96
0.9	100	6.62	2.34
	150	4.892	2.57
	200	3.935	2.75

5. CONCLUSIONS

Hydraulic fracture job plays a significant role in increasing the production from extremely low permeability oil reservoirs. The developed SMART software efficiently designs HFJ and is capable of performing pre- and post-frac analysis. The obtained results show that with the increase in fracture half-length, the production from a reservoir having any permeability also increases. But the percentage increase in production decreases with reference to further increase in x_f, therefore an optimum value of fracture half-length should be selected. It has also been observed that the hydraulic fracture job is more feasible in terms of flow rate increase in tighter formations on comparative basis. Therefore, proper designing and execution of HFJ coupled with reservoir performance analysis can provide/ act as an attractive solution to increase the production rates of wells in extremely low permeability oil reservoirs.

6. NOMENCLATURE

F_{CD} Dimensionless fracture conductivity
J Productivity index
J_o Original productivity index
k Formation permeability
k_f Fracture permeability
P_b Bubble point pressure
P_R Reservoir pressure

P_{wf} Reservoir pressure

q Production rate

q_b flowrate at bubble point pressure

q_{max} Maximum production rate

r_e External/ drainage radius

r_w Wellbore radius

s_f Equivalent skin factor

w fracture width

Average fracture width

x_f Fracture half-length

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