Effect of Hydraulic Fracture on the Fractured Reservoir Based on the Connection with Natural Fractures

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Abstract

Hydraulic fracturing in the fractured reservoirs plays a significant impact on the production rate. In this study, the hydrostatic condition is taken into account, the hydraulic fracturing operation was applied in every direction usinga written distinct element code. In each direction the hydraulic fracture is applied with different lengths and in each level the amount of production is predicted. The impact of interaction of natural fractures and hydraulic fractures on the amount of production is discussed and the number of natural fractures which are intersected by hydraulic fractures is presented. Hydraulic fracturing operation in different directions with different lengths is economically analyzed. In fractured reservoirs the best scenario that is the hydraulic fracture is created in a direction that intersects a group of high permeable natural fractures/parts of the reservoir that are actively participating in flow or the parts with high pore pressures and no connection to the well. is The reasonthat connecting the natural fractures which are near the well does not have a significant effect on the production rate. According to the results, creating the hydraulic fractures in a direction with no fractures significantly affects the production rate.

Keywords: Fluid flow, Hydraulic fracture, Natural fracture, Pore pressure, Production rate, Stresses

Introduction

The purpose of hydraulic fracturing is to enhance the productivity index in production wells and injectivity index in injection wells. Productivity index is defined as the rate of down hole production in a specific pressure drop between the reservoir and the well. Moreover, injectivity index is defined as a rate in which the fluid, with a specific pressure drop between reservoir and well, is injected into the well. New diagnostic tools developed during the last decade strongly suggest multiple fracture propagation or multi-stranded hydraulic fractures in naturally fractured reservoirs [1]. Dynamic fracture mechanics theories indicate that crack tip branching will occur only in cases where fracture propagation speed is comparable to the seismic velocity of the material (more precisely, the Rayleigh wave speed). However, field data demonstrate that hydraulic fractures propagate much more slowly than seismic wave [2], so multi-branched fracturing should not occur in a homogeneous, isotropic, intact rock mass. On the other hand, the present day in-situ tectonic stress direction can be rotated from the time of the formation of natural fractures [3]. So, natural fractures are not necessarily aligned with the present day direction of maximum compressive stress. Thus, natural fractures may not be parallel with hydraulic fracture and might be intersected by the hydraulic fracture. Intersection with geological discontinuities such as joints, bending planes, faults and flaws in reservoirs, might render non-planar and multi-stranded. Fractures whose branching and segmentation are frequently observed phenomena in outcrops [4]. During production, the complex induced fracture paths [5] may lead to higher pressure drops, causing the drainage radius of the stimulated well to become less than the predicted value for an idealized fractured well. In extremely low

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permeability reservoirs like shale, however, fracture pattern complexity may lead to higher recovery [6].

In this study, hydraulic fracturing operation is being studied in a naturally fractured reservoir whose fracture distribution is uniform. For this reservoir, hydraulic fracturing operation in various directions is simulated. In each direction that the operation is performed, fracture lengths are considered different. In each direction with different lengths, production rate is evaluated and the reason of the changes in production rate is discussed. Finally, the most optimized direction and length which causes the highest production rate is specified and the reason of the other unacceptable scenarios is also specified in economical and operational dimensions.

1- Methodology

Simulation model

The condition of natural fractures around the well is simulated with distinct element code (Figure1). As it is seen in Figure-1 in this simulation only natural fractures which are connected around the well are shown. In other words, in regions where thenatural fractures cannot be appearedthere is a fracture which is separated and not connected to the other fractures.

We need a series of complete reservoir information because in each stage of examining the effect of a certain parameter, only that parameter is changed and other parameters should remain constant. This information is presented in Table1. The information of both reservoirs is considered equally because only the effect of length and aperture are evaluated.

The presented model is two dimensional which consists of a 15×15 meters block in x-y dimensions with a well at its center. It is assumed that hydraulic fracture is just applied in production layer and all parameters are constant and the only variable is hydraulic fracture length and its direction. Fracture aperture in each stage is constant and equals to 50 micrometer (the least amount suitable for fluid transfer) and reservoir fluid density of 20 kg/m^3. Four nodes are introduced to the well in order to measure the fluid rate into the well. Two of them are placed in the ceiling and two others in the wall in front of each other.

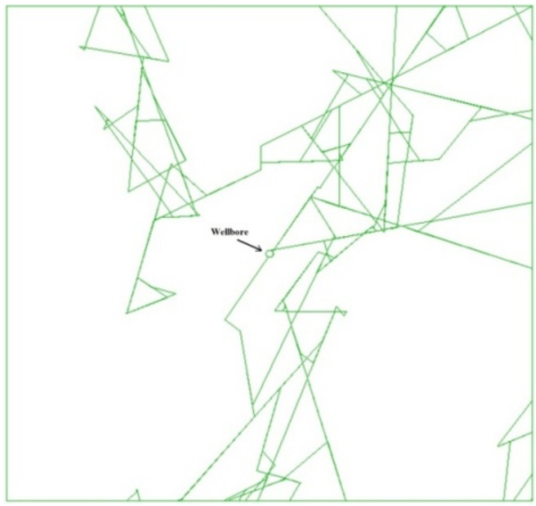

Figure 1: Situation and condition of natural fractures around the well

2- Hydraulic fracture direction

The most important characteristic to be measured for hydraulic fracturing is in-situ stresses because they affect operation in many ways. Their strength and direction are very important. Depending on the direction the fracture plane appeared in the wellbore, is created horizontally or vertically.

Fracture direction is normal to the minimum resistance plane, that is represented by the absolute minimum stress. Knowing about the stress regime is of great concern for predicting the hydraulic fracturing process [7, 8]. Borehole breakouts and its fractures [9-11], micro seismic events [12-15] and stimulation pressures [16-18] have been evaluated to confine the orientation and amplitude of the principal stress components. Therefore, as a conclusion the horizontal stress would be smaller than the vertical and normal to the minimum stress direction (Figure 2).

Table1: Simulation data

General Information	
Selectively block dimensions	8×8 m
Pressure gradient	300 Psi
Well diameter	8.5 in
Reservoir fluid density	20 kg/m^3
Bulk modulus of reservoir fluid	1e6
Properties Of Intact Rock	
Density	1800 kg/m3
Shear modulus	20 e9
Fracture Properties	
Normal hardness of fracture	400 e9 (stress/displacement)
Shear hardness of fracture	400 e9 (stress/displacement)
Friction angle	30°
Permeability of fracture	100، ml Darcy
Fracture opening when the normal stress is zero	50e-6 m
Structural model of fracture	Coulomb

In this model, we assume that the distribution of principle stresses around the well is equal. It means that the maximum and minimum principle stresses are assumed equal.

According to this hypothecs the hydraulic fracturing can be performed in either direction. Here, the hydraulic fracturing operation is conducted in four directions with the angles of 0^o, 45^o,-45^o,90^o. A schematic view is shown in Figure-3.

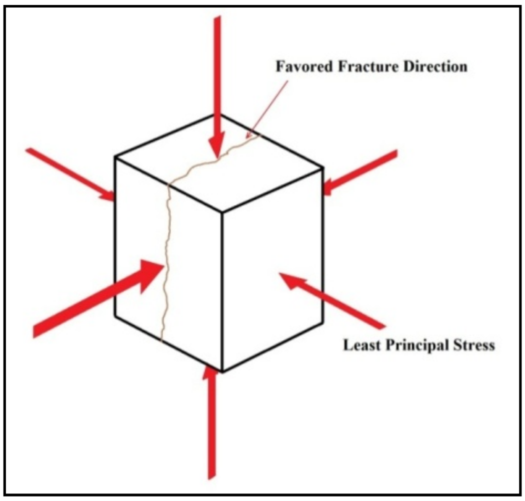

Figure 2: Direction of hydraulic fracture based on principle stresses

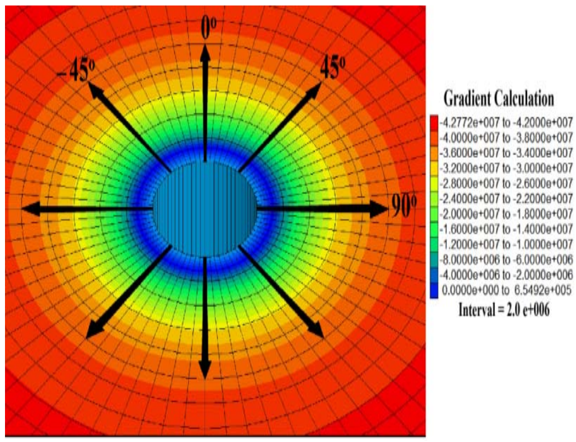

Figure 3: Directions of hydraulic fracturing exertion in reservoir

3- Hydraulic fracture operation

3-1-Hydraulic fracturing in direction of 0 degree

Hydraulic fracturing operations in zero degree direction with lengths of 3,6,9,12,15 meters are shown in Figure 4. As it is shown, there is the hydraulic fracture with length of 3 meters in the Figure. It is because a hydraulic fracture with this length does not cross or connect to any natural fracture in the reservoir. The production rate in each length of hydraulic fracture is shown in Figure 5.

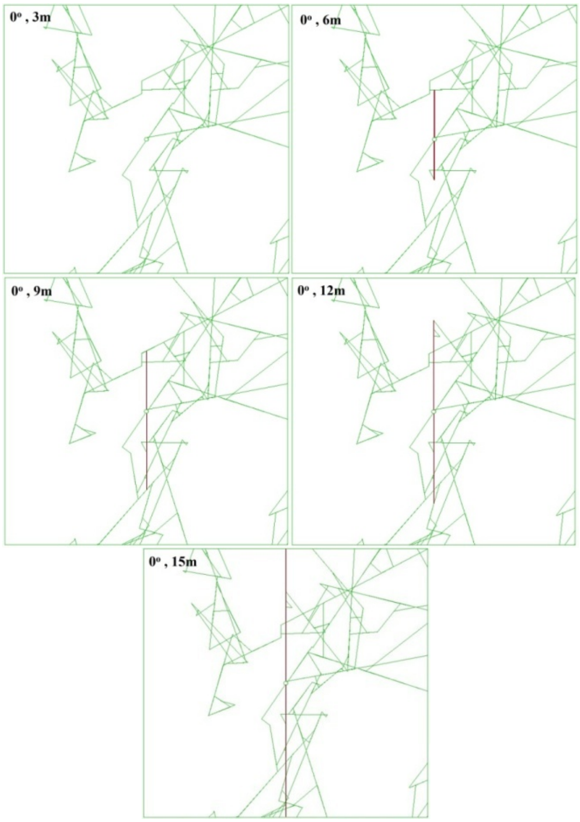

Figure 4: Hydraulic fracturing operation in zero degree direction with different lengths

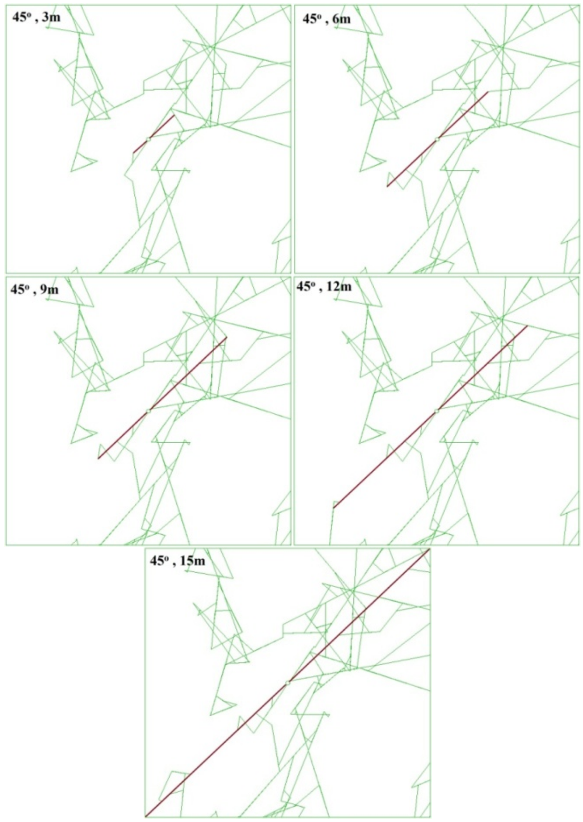

Figure 6: Hydraulic fracturing operation in direction of 45degrees with different lengths

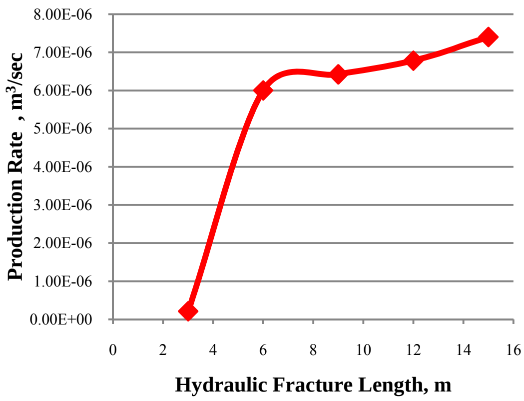

Figure 5: Production rate with and without hydraulic fracture with different sizes in the direction of 0°.

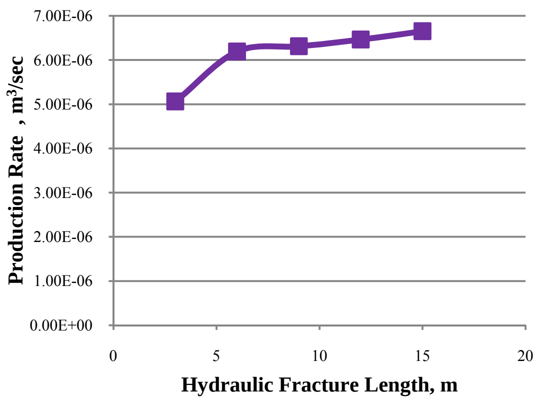

Figure 7: Production rate in normal conditions with exertion of hydraulic fracture with 45degrees direction and different lengths

3-2-Hydraulic fracture in the direction of 45 degrees

A schematic view of hydraulic fracturing operation with different lengths in 45° direction is shown in Figure6.

Production rate curve in normal conditions and with exertion of hydraulic fracture with 45degrees direction and different lengths can be seen in Figure 7.

As we can see in Figure 8, after exertion of hydraulic fracture with length of 6 meters, with increasing the fracture length, production rate does not significantly increase. From the Figure 6 it can be seen that in the direction of hydraulic fracture there are only separate natural fractures and they don’t have an influence on the fluid flow into the hydraulic fracture. In other words, these separate natural fractures play a very little role in increasing production because they are not connected to other natural fractures. In a direction which there is an accumulation of natural fractures, a hydraulic fracture can be connected to them and as these natural fractures are also connected to the well, they will probably cause an increase in production. Figure 8 shows the condition and direction of the main flows in the process of hydraulic fracturing operation with the length of 15 meters and direction of 45-degrees from the normal.

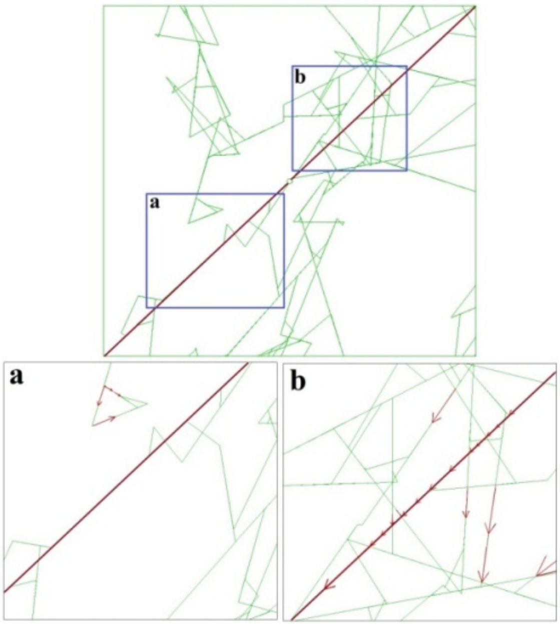

Figure8: Fluid flow condition after the exertion of 15 meter hydraulic fracture in the direction of 45degrees

3-3-Hydraulic fracture in the direction of 90degrees

Hydraulic fracturing with different lengths in 90degrees direction is shown in the Figure 9. Here there are also separate natural fractures which appear in the Figure when the hydraulic fracture intersectsthem. Production rate in this operation is shown in Figure 10.

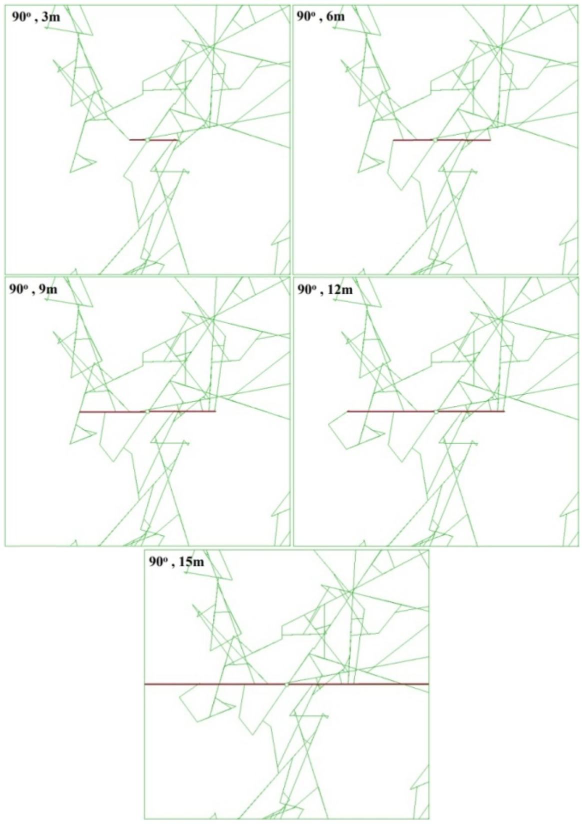

Figure9: Hydraulic fracturing with different lengths in 90degrees direction

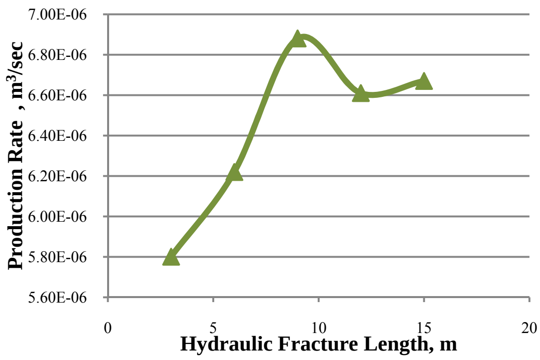

Figure10: Production rate with and without hydraulic fracture with different lengths in the direction of 90 degrees

Similar to the previous ones, in this case we also expected the production length to be increased with increasing the hydraulic fracture length. But according to Figure10 with increasing hydraulic length from 6 to 9 meters, the production rate stops to be increased. However when the length reaches 12 meters the production rate decreases. When the length reaches 9 meters, in fact it crosses natural fractures which enhance the production (Figure11). In 9metersfracture length all the main flows are practically in the direction of hydraulic fracture which results in the increase of production rate. But when the fracture length reaches 12 meters it crosses some separate natural fractures which results in the decrease of production rate (Figure12). As we can see in Figure13, connection to these natural fractures causes some changes in fluid flow. It is because of the permeability and location of these natural fractures relative to the hydraulic fractures. In this condition the fluid flows are from hydraulic fracture to the natural fractures. This causes a reduction in production rate. When the fracture length reaches 15 meters the increase of production rate becomes negligible.

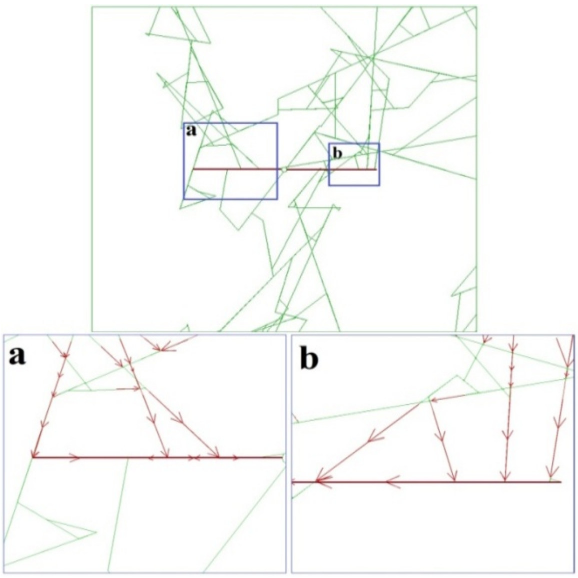

Figure11: Schematic view of flow condition between natural and hydraulic fracture with 9 meters length and 90degrees direction

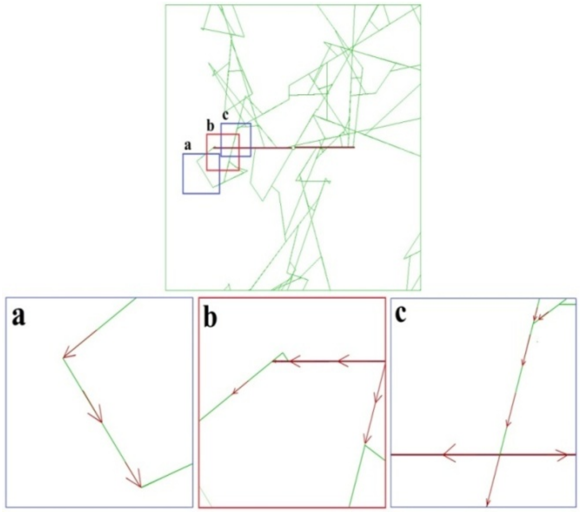

Figure12: Schematic view of flow condition between natural and hydraulic fractures with 12 meters length and 90degrees direction

3-4- Hydraulic fracturing in the direction of minus 45degrees

Fracturing operation in minus 45degrees direction with different lengths is shown in Figure 13 and production rate is also shown in Figure 14.

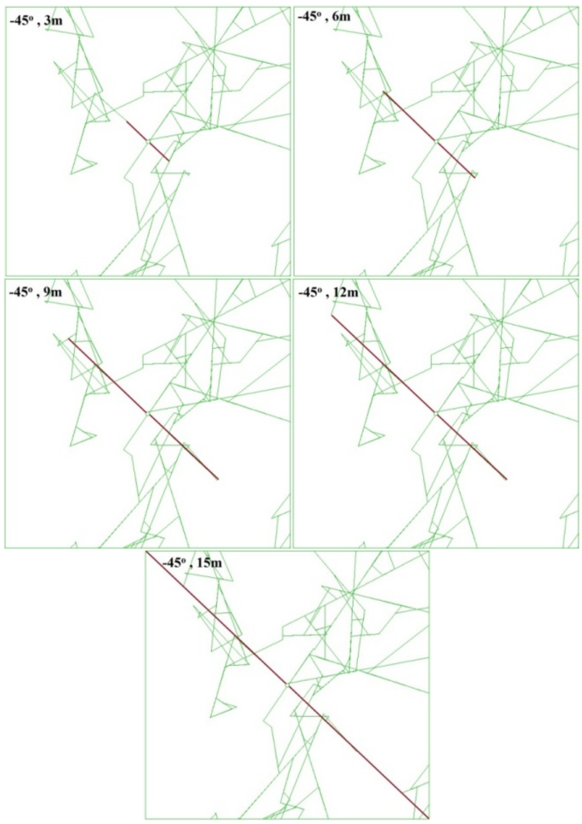

Figure13: Hydraulic fracturing in -45degrees direction with different lengths

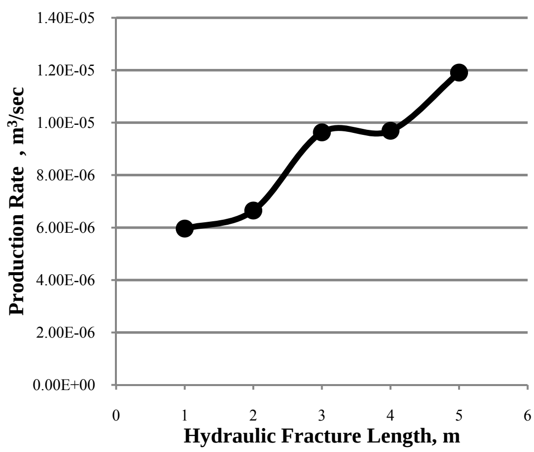

Figure14: Production rate with and without exertion of hydraulic fracture with different lengths in the direction of -45degrees.

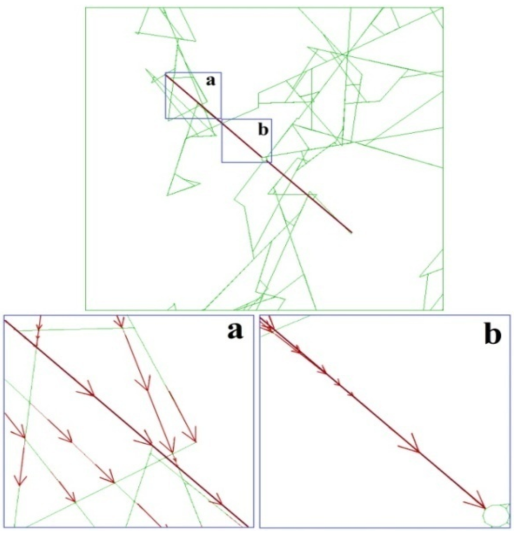

Figure15: Flow condition between natural fractures and a hydraulic fracture with length of 9 meters in the direction of minus 45 degrees

According to Figure 14 and exertion of a fracture with length of 3 meters in minus 45degrees direction, the production rate shows a significant increase. As it can be seen in Figure 13, a 3 meters length hydraulic fracture connects the group of natural fracture to the well which previously didn't have a connection with well. The more important point is that when fracture reaches 9 meters, a noticeable increase in production is appeared. If we observe the connection point of hydraulic and natural fractures (Figure15), it becomes clear that this hydraulic fracture connects a group of natural fractures, which are away from the well, to the well. On the other hand hydraulic fracture with length of 15 meters can connect the further group of fractures to the well which causes a further increase in production.

4- Result and discussion

The important point is that the other natural fractures which are connected to hydraulic fractures with the fracture coalescence phenomenon are also considered.

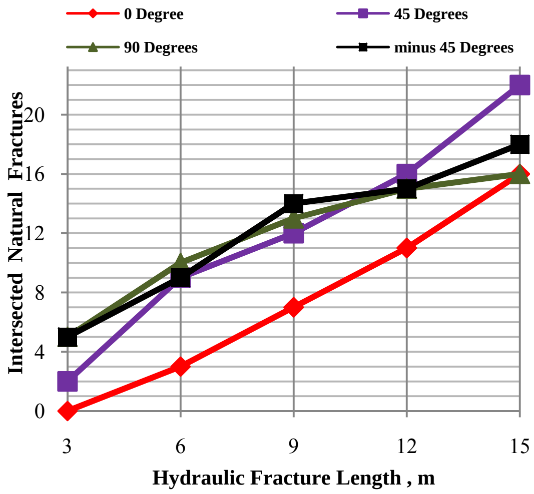

Figure16: Number of intersected natural fractures with hydraulic fracture

If we pay attention to the main flow conditions without hydraulic fractures in natural fracture system around the well (Figure17) or the pore pressure condition of natural fractures (Figure18) we can see that if the hydraulic fracture is exerted in a direction which connects to the natural fractures with high permeability that are far from the well it can affectthe production rate. From the Figure 18 it can be seen that the fractures with high permeabilitythat are away from the well possess large amounts of fluid. It can also be seen in Figure 18 that as natural fractures have higher pore pressure, they contain more fluid flow. With comparison ofFigure17 and Figure18, it can be seen that only the regions which have higher pore pressures contain main flows.

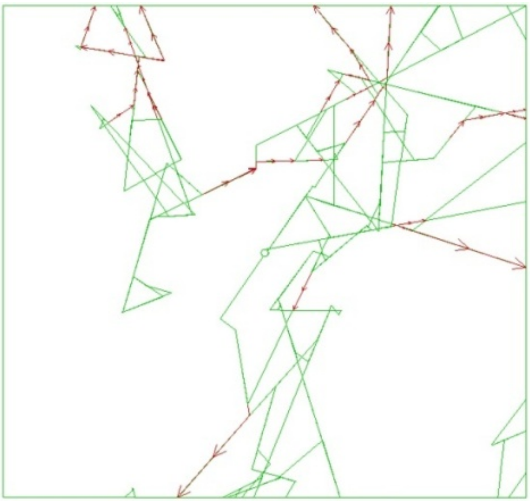

Figure17: Condition and situation of main flows in natural fractures around the well

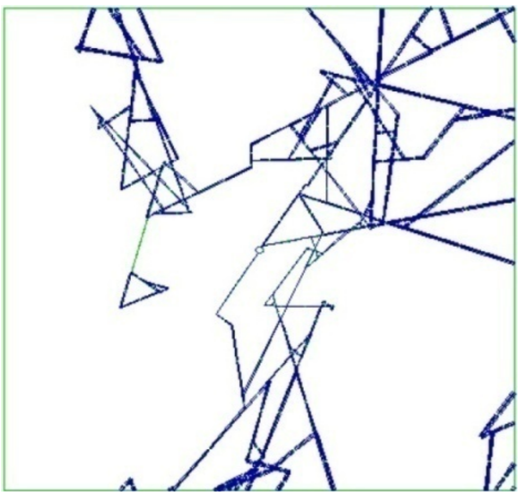

Figure18: Pore pressure condition in a system of natural fractures around the well

When a hydraulic fracture with the length of 9 meters and minus45degrees direction isexerted, it crosses the natural fractures with high flow and permeability and production rate suddenly increases. In the same direction, the length is extended to 15 meters, the hydraulic fracture crosses further fracture groups and production will be increased more. This can also be seen in 15 meters long fractures with 90 degrees direction.

In fractured reservoirs, exerting hydraulic fractures in a direction where there aren't enough natural fractures, is not suitable as they don't participate in production (for example 12 and 15 meters hydraulic fractures with 90degrees direction).

If the length of a hydraulic fracture is designed in a way that only affects natural fractures around the well, then this operation does not affect the production because these fractures normally participate in production(hydraulic fractures with lengths of 9,12,15 meters in 45degrees direction).If we consider this case economically then perhaps Figure 19 would better explain this matter. If the length of hydraulic fracture is more, the operation cost will be more. If production rate increase is acceptable this increase in the cost will be compensated.

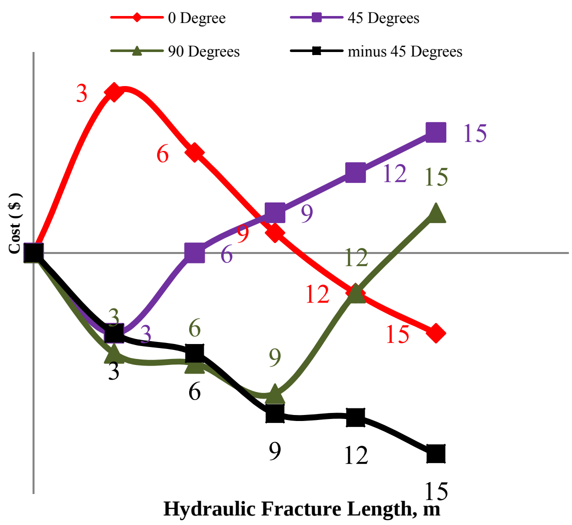

Figure19: Hydraulic fracture length versus the cost in different stages of the hydraulic fracture design

When the 3 meters long hydraulic fracture was applied in the hydraulic fracture operation, there was no change in production due to disconnectedness between hydraulic fracture and any other natural fractures. As the length of the fracture starts to increase, it leads to increase of production rate and as a result the costs begin to decrease. Therefore, designing hydraulic fracture operation in 0degree direction with 3meters length only increases the costs and has no effect on production. Hydraulic fracturing operation with 45degrees direction is not recommended because natural fractures in this direction are close to well and their further connection does not have a significant effect on production. Hydraulic fracturing in 90 degrees direction is affordable up to 9 meters length beyond which, it connects to some parts of the reservoir whit no fracture accumulation. Hydraulic fracturing in minus 45 degrees direction gives an acceptable increase in production in all of the designed lengths because increasing the fracture length will connect highly permeable natural fractures to the well which consequently increases theproduction rate.

5- Conclusion

The main results of this study are:

1- Hydraulic fracturing operation in fractured reservoirs can increase the production rate.

2- If the fracturing operation is conducted in a direction that it just connects the natural fractures near the well, it cannot significantly increase the production rate because the natural production of reservoir is from these natural fractures and fracturing operation in these directions does not make sense.

3-Applying hydraulic fractures in the parts of reservoir that contain few natural fractures does not increase production rate and even raise the operation costs.

4- Fracture length increase does not always causes production increase and cost reduction and the most optimized operation state does not happen with the longest fracture length. Everything depends on the longest hydraulic fracture which can connect high permeable natural fractures to the well.

5- Extending a fracture in a direction which is in the way of a group of fractures that are not connected to the well can give the most optimized operation state.

6-Hydraulic fracture formation in the direction of remote natural fracture groups with high pore pressures is the most optimized state. Afracture with minus 45degrees direction could connect one part of these regions to the well and ,therfore it was the most optimized direction to increase the production and reduce the costs.

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