Analysis of hydraulic fracturing in fractured reservoir: interaction between hydraulic fracture and natural fractures

Jaber Taheri Shakib[1], Abdolvahed Ghaderi[2] and Abbas Abbaszadeh Shahri[3]

[1]Department of Petroleum Engineering, Shahid Bahonar University of Kerman, Iran
(Jaber_Taherishakib@Yahoo.Com)
[2]Department of Petroleum Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[3]Assistant Professor, Department of Geophysics, Islamic Azad University, Hamedan Branch, Hamedan, Iran
*Corresponding author: Abbas Abbaszadeh Shahri
E-mail: a_abbaszadeh@iauh.ac.ir; abbas4646@yahoo.com

Abstract: Hydraulic fracturing operations in fractured reservoir, due to the complex nature of these processes require different parameters of hydraulic fracture and also studying the reaction between hydraulic and induced fractures. In this study, at first analysis of the hydraulic fracture length and its height from the point of impact on production flow rate will be evaluated. Then, in some areas of reservoir the reaction between natural and hydraulic fractures will be discussed. Interactions among three natural fractures of the angles 90, 45 degrees and one parallel with hydraulic fractures (zero degrees) will be analyzed. In this review, including tensile and shear debonding two types of reactions will be checked. Debonding phenomena at various distances before contacting the hydraulic fracture and also after reaching and being intersected by natural fracture by hydraulic fracture will studied. As we will see, depending on the natural fracture from point of their location angel relative to hydraulic fracture we have different tensile and shear debonding.

[Jaber Taheri Shakib, Abdolvahed Ghaderi and Abbas Abbaszadeh Shahri. **Analysis of hydraulic fracturing in fractured reservoir: interaction between hydraulic fracture and natural fractures.** *Life Sci J* 2012;9(4):1854-1862] (ISSN:1097-8135). http://www.lifesciencesite.com. 282

Keywords: Fracture, Debond, Tensile, Shear, Kick point , Opening

Introduction

One way to exploit the fractured reservoir to increase production rates is connecting of natural fractures to well. The most important way to achieve this goal is the influence physics of reservoir rock that is trying to improve the physical structure of reservoir rock. Among the most important of these methods can be used to create artificial fractures in the reservoir rock. Artificial fracturing is one of the common methods in order to stimulate wells to increase the production of oil and gas. In hydraulic fracturing, there is some fractures made from well wall to oil and gas formations. With this operation, the natural fractures associated with each other via the hydraulic fracturing and finally are connected to the well.

Pre-existing natural discontinuities in the rock also affect the propagation path of a hydraulic fracture. There are several numerical techniques that are proposed to model such complicated process, some of them are based on finite element method (Zhang and Ghassemi , 2010), others are based on combining analytical and numerical methods (Weng et al. 2011). However, these methods either show problems of dealing with complicated, highly fractured reservoir models and a comprehensive analysis of how different parameters influence the fracture behavior has not been fully investigated to date. In most other cases, successful shale-gas production requires hydraulic fracturing to improve wellbore-to-natural fracture system communication, which eliminates the high near-wellbore pressure gradient. Additionally, coring has shown that hydraulic fractures have been diverted along and have propped pre-existing natural fractures (e.g. Hopkins et al., 1998 and Lancaster et al. 1992). Therefore, understanding the geometry and the growth process of hydraulic fractures and their interaction with natural fractures is important for designing, monitoring and assessing the induced fractures and their effects on the wellbore production.

There are several numerical techniques that are proposed to model such complicated process, some of them are based on finite element method (Zhang and Ghassemi , 2010), others are based on combining analytical and numerical methods (Weng et al. 2011) or multi-stranded hydraulic fractures in naturally fractured reservoirs (Fisher et al. 2005). Dynamic fracture mechanics theories (Freund 1990) indicate that crack tip branching will occur only in cases where fracture propagation speed is comparable to the seismic velocity of the material.

In this study, progress of hydraulic fracture in the fractured reservoir is reviewed. Development of hydraulic fracture in fractured reservoir with distinct element method, and the reaction between the natural and hydraulic fractures with extended finite element method are done. As we will see the hydraulic fracturing operation in fractured reservoir, depending on the length and height can have a significant impact on production. The reaction between the natural and hydraulic fractures in reservoir depending on the contact angle and close of induction fracture is different.

Model Description

By using a distinct element method, the area around the wells that studied is simulated. The simulation by using field data such as core, Logging, and ... Has been done. Figure 1 shows the model simulation by use of distinct element code. As can be seen in figure 1 the natural fracture stated around the hole is completely specified. The block size is 20 x 20 meters that the well is located in the middle of the block.

Status of natural fractures in different areas around the well is not the same and hydraulic fracturing in each direction along the course that will produce different results because in any direction or angle, position and density of natural fractures varies. So here's the principle stress distribution around the well to form hydraulic fracture is characterized. Stress fractures parallel with maximum principle stress and perpendicular to the main stress of the minimum are extended. Based on the main stress distribution around the studied wells, hydraulic fractures at the angle of zero degrees are formed then extended (Figure 2).

Figure1. Model of the fractures around the well

In naturally fractured reservoirs fluids generally exist in two systems (1) the rock matrix, which provides the main bulk of the reservoir volume and storage and (2) the highly permeable rock fractures which provide the main path for fluid flow. If the fracture system is assumed to provide the main path and storage for fluid, i.e. it is not connected to the matrix system, this can be considered as a single-porosity single-permeability system (SPSP) as in Figure 3-a. On the other hand, if we assume that the fluid flow in the reservoir takes place primarily through the fracture networks while the matrix-blocks are linked only through the fracture system, this could be regarded as a dual-porosity single-permeability system (DPSP) as in Figure 3-b. In addition, if there is flow between matrix-blocks, this can be considered as a dual-porosity dual-permeability system (DPDP) as in Figure 3-c. Clearly, the dual porosity dual permeability system is the most general approach to modeling fractured reservoirs and will reduce to the dual-porosity system when flow in the matrix block is assumed to be negligible (Ahmed H et. 2004). In this model consider one-phase incompressible flow in a SPSP system.

Performing hydraulic fracture design calculations under these complex conditions requires modeling of fracture intersections and tracking fluid fronts in the network of reactivated fissures. In this dissertation, the effect of the cohesiveness of the sealed natural fractures and the intact rock toughness in hydraulic fracturing are studied. Accordingly, the role of the pre-existing fracture geometry is also investigated. The results provide some explanations for significant difference in hydraulic fracturing in naturally fractured reservoirs from non-fractured reservoirs. For the purpose of this study, an extended finite element method (XFEM) code is developed to simulation fracture propagation, initiation and intersection. The motivation behind applying XFEM are desirable to avoid retesting in each step of the fracture propagation, being able to consider arbitrary varying geometry of natural fractures and the insensitivity of fracture propagation to mesh geometry. New modifications are introduced into XFEM to improve stress intensity factor calculations, including fracture intersection criteria into the model and improving accuracy of the solution in near crack tip regions (Arash dahi 2010).

Analysis of length and height of the hydraulic fracture

After determining the formation direction of hydraulic fracture by using distinct element method, hydraulic fracture with different length and height will be applied in reservoir. Production flow chart when hydraulic fracture is applied is given in Figure 4.

As can be seen when the fracture length is equal to 2, 4 and 6 meters, the production in different aperture is almost same. If looked at the area around the wells that the hydraulic fracturing with these lengths are located, it is observed that the hydraulic fracture is located in intact area and increased to 6 meters in length practically does not interrupt the natural fracture. By increasing hydraulic fracture length, more natural fractures will connected to well. If we see the chart we can conclude that the length play more important role, and production shows more sensitive then length and approximately after 200 micrometers opening, with an increase of this parameter the production is almost constant. During fracturing of the low-permeability fractured reservoir, the fracture length is more important than the flow conductivity (Z. Zaho et al., 2005).

Obviously, because the number of natural fractures in path of hydraulic fractures are a few, so the length plays more important role and increase in aperture to formed fracture have low effect on production. In other words, if hydraulic fracture in fractured reservoir expands in area where the natural fractures with low density are existing Induction fracture with more length will have a better performance.

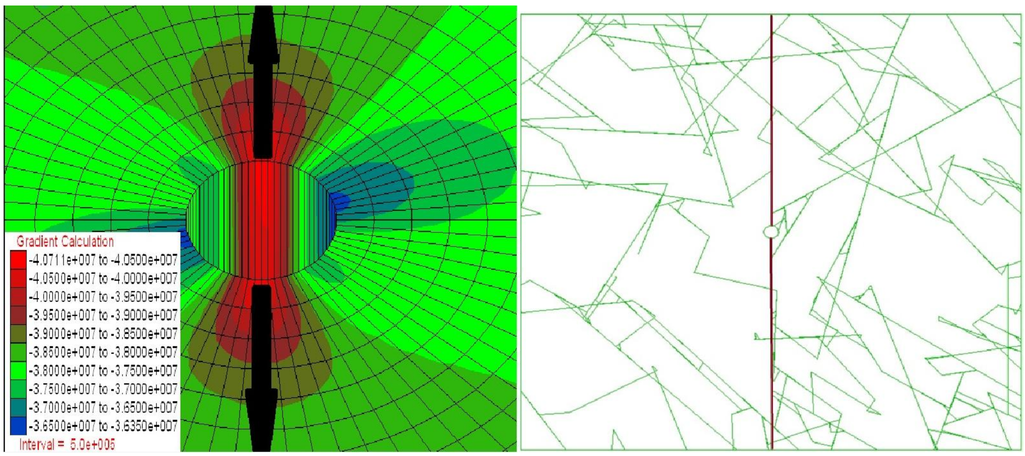


Figure2. The formation and expansion of hydraulic fractures in studied well

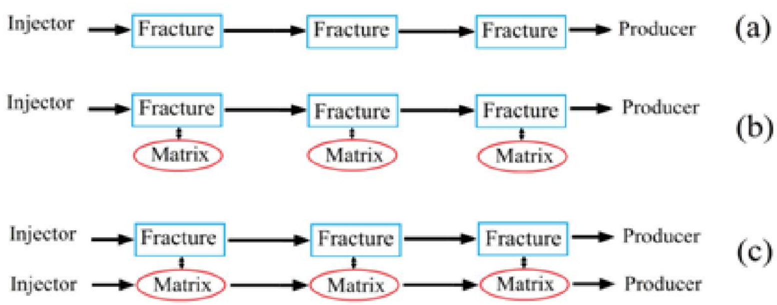


Figure3. a) Single-Porosity Single Permeability System b) Dual-Porosity Single-Permeability System c) Dual-Porosity Dual-Permeability System.

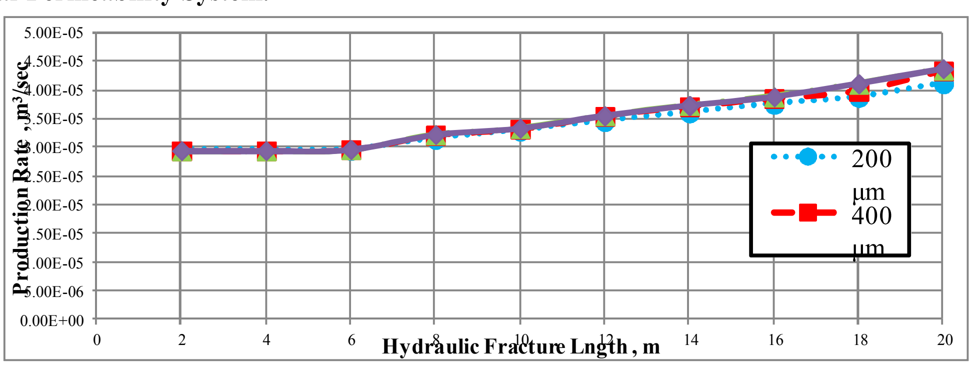


Figure4. Flow diagram of production of different length and height of the applied hydraulic fracture

Reaction analysis between Induced fracture and natural fracture

With the expansion of hydraulic fracture in fractured reservoirs, different reactions between natural fracture and hydraulic fracture will occur. This reaction is different due to various collisions that made between induction fracture and natural fracture. Based on the angle of collision, the reaction will be different. Here we study three types of collisions that occur with expansion of hydraulic fractures in reservoir. Figure 5 shows the three types of collisions. Here we only consider reaction between hydraulic fractures and natural fractures. In other words, another natural fracture near the studied fracture may be present but we assume in any angle a natural fracture with hydraulic fracture reacts.

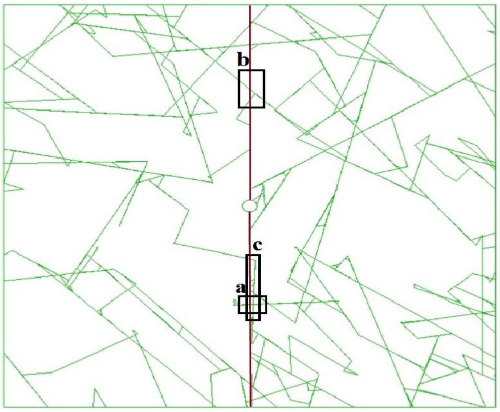


Figure5. 3 types of collisions between hydraulic fracture and natural fracture (A: angle of 90 degree, B: angle of 45 degree, C: angle of 0 degree)

The natural fractures will open if the energy of the growing hydraulic fracture is large enough to deboned (re-open) fracture cements. Debonding can also take place ahead of the primary crack before the fractures intersection. The natural fracture starts to open/shear or propagate before the hydraulic fracture arrives because of near-tip stress concentrations. If this phenomena, it may even divert the growing fractures into double-deflection in the natural fractures.

When the hydraulic fracture with 90-degree angle will close to the natural fracture, according to Figure 6, when the hydraulic fracture reach to a, b and c areas debond of natural fracture will evaluate. a and b areas are located respectively 10 and 5 cm away from natural fracture and c area is exactly located where the natural fracture and hydraulic fracture are reached together. Natural fracture length of 50 cm is considered and stress condition is assumed isotropic.

When the hydraulic fracture is close to a natural fracture two debond in natural fracture occurs: Shear failure and tensile failure. Debond review in natural fracture is from north to south of natural fracture.

The opening and sliding displacements along the debonded crack (90 degrees) is shown in figure 7. It is remarkable that the debonding length and the stress intensity factors at the tips of primary fracture or new initiated fracture are independent of the rock stiffness, because the stress field of the growing fracture is independent of rock elastic properties.

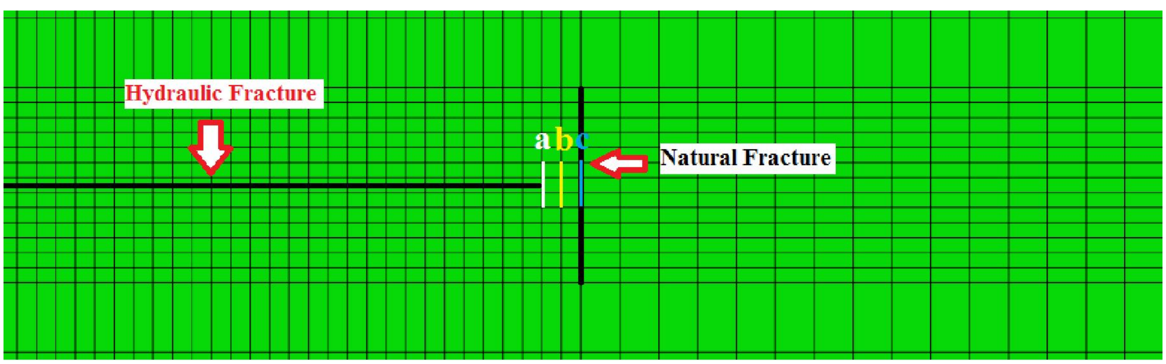
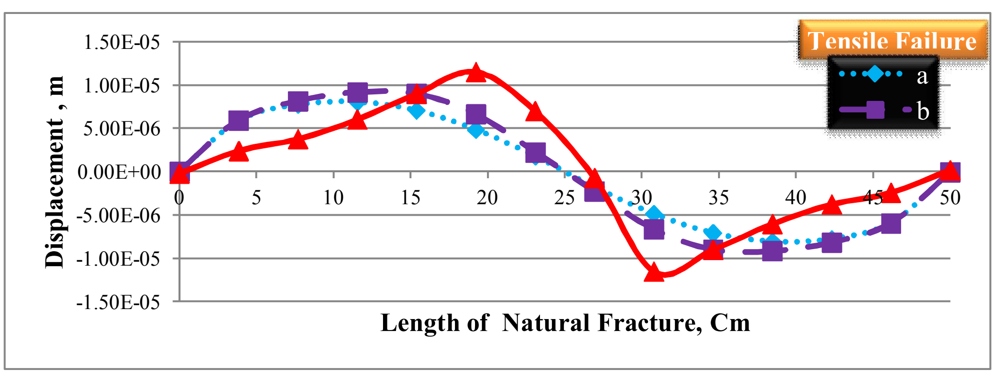


Figure6. Evaluated areas for debond of natural fracture when induction fracture with 90-degree angle



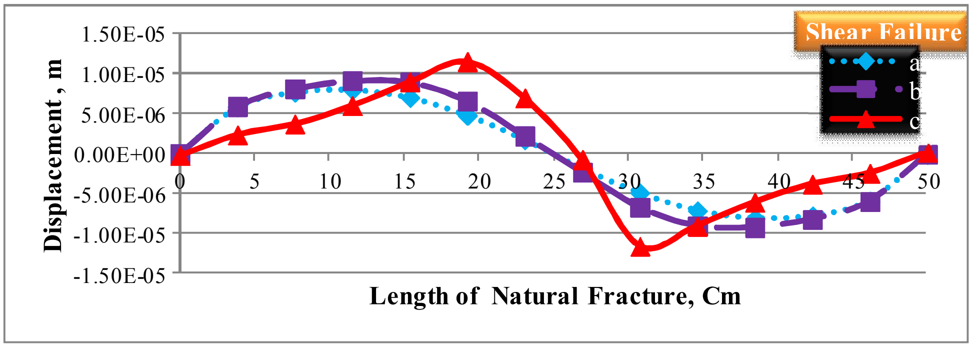


Figure7. Opening and sliding displacements along the deboned zone of Figure 6

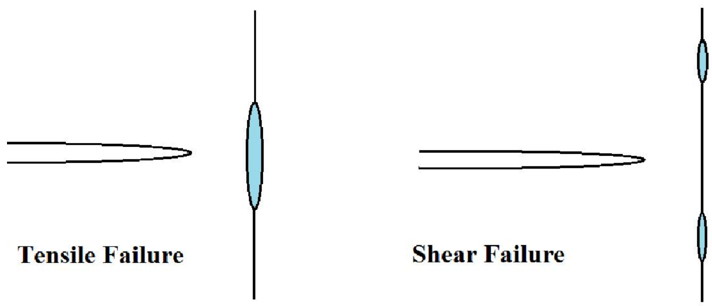


Figure8. Schematic illustration for debonding induced by the approaching crack

relative to the natural fracture spread

When the hydraulic fracture is close to the natural facture opening displacement in an area of natural fracture expands that on these area or point the natural fracture will reach and cut it (kink point) and sliding displacement in the region without the kink point above or below this point spreads (Figure 8). It is noteworthy that if the distance between induction fracture and natural fracture are less focus of debond phenomenon will be more. In other words, in the opening displacement, the central region of debonded zone by closing of induction fracture will have more expansion and sliding displacement in the region near the kink point in the debonded zone expands.

For the case of non- normal intersection, the induced debonding is asymmetric with respect to the approaching crack and may possibly become partly closed under the effect of the approaching fracture. In non-normal cases, shear failure plays a significant rule in activating the fractures and forming asymmetric debonding with respect to the approaching crack. This observation can be justified by comparing figure 9, where non-normality amplifies the shear traction exerted on the natural fracture.

Figure 9 show Normal and shear tractions ahead of the declined primary crack (45 degrees) that are experienced along the sealed crack at different distances to the middle of the seal crack: 1.0, 0.5 and 0.05 respectively (distances and tractions are normalized with respect to growing fracture length and pressure, respectively). These plots were compared with XFEM results.

To investigate the phenomenon of debond, when a natural fracture with a 45 degree angle placed in hydraulic fracture path as same as 90 degree we assume 3 regions (Figure 10). But here is difference that related to c area because here c is the exact moment that the hydraulic fracture cut the natural fracture.

The opening and sliding displacements along the debonded crack (45 degrees) is shown in figure 11. When the induction with 45-degree angle is close to the natural fracture in c area, tensile failure phenomenon is such status that the natural fracture had a 90 degree, because the middle area of natural fracture become debonding and maximum value of debonding and is at the kink point. But with less distance between natural and induced fractures the condition is slightly different. When the hydraulic fracture reach to b area, the end of natural fracture compressed (about 12 cm end of natural fracture) and other parts of natural fracture become debond. Maximum value of deboning and it is at the kink point but the symmetry of the debonding zone in natural fractures we have seen with 90-degree angle, it is not here. After being cut off the natural fracture by hydraulic fracture (c area) upper part of kink point become debonding and lower part compressed (figure 12).

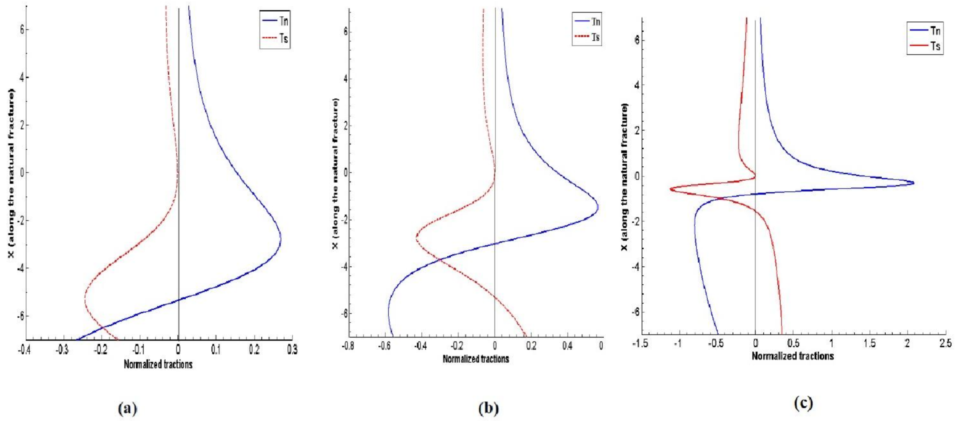


Figure9. Normal and shear tractions ahead of the declined primary crack (45 degrees)

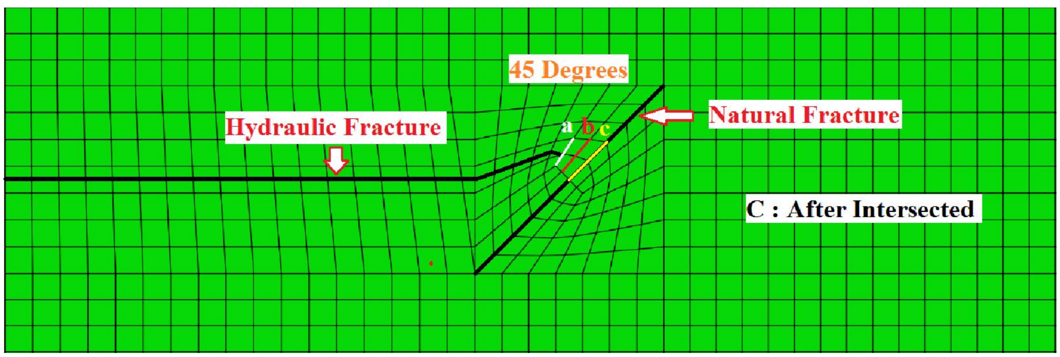


Figure10. Areas of study for Debond investigation when natural fracture with a 45 degree angle relative to the hydraulic fracture spread

According to shear failure chart of Figure 11, when the induction fracture reaches a area slide debonding in all over natural fracture in same path but its amount was quite variable and it is not symmetric So that the state has taken the form of a wave. In lower part of natural fracture the shear failure amount is up. By reaching the induction fracture to b area, the shear failure condition get more symmetric and maximum of slid debonding in near of kink point occur, and here the lower part of fracture has more slid debonding then upper part. After cutting the induced fracture by the natural fracture, the situation is quite different(c area) and the direction of shear failure in both side of kink point is not parallel and even at upper part of natural fracture the direction of slide debonding become negative then to kink point become positive and maximum statues of slide debonding in near of kink point at upper part of fracture occur. But a point that needs to be noticed is that after cutting the natural fracture in the lower kink point slide debonding direction is negative there are swinging and nearly 3 points to this slide debonding reaches its largest value in the area. The fracture deflected by non-normal intersection have an asymmetric opening which directs the fluid toward the direction going farther from the primary fracture so double-deflected fracture will tend to propagate on just one-side. The next stages of fracture propagation after debonding is complicated as the fracture propagation will be dominated by many factors such as anisotropy of tectonic stresses and the size and orientation of the debonded length with respect to tip of hydraulic fracture. Shum and Hutchinson (1990) and Hutchinson (1987) studied the crack tip shielding and anti-shielding by parallel en echelon offsetting cracks. However their analyses were limited to uniform far-field loading which is not the case for hydraulic fracture but it may represent high permeability reservoirs case, where both fractures could be pressurized. The crack debonding phenomena may also occur in parallel (and sub parallel) fractures as well. In such situations, the effect of the re-opened fractures is complicated.

At this stage, we examine condition of natural fracture debonding when placed in parallel with hydraulic fracture. As can be seen in Figure 13, we here consider the three areas. Fracture Coalescence phenomena, occur in this case with the expansion of hydraulic fracture extremely function of parameters such as stress distribution, the vertical distance between natural and induced fractures, length of natural and hydraulic fractures.

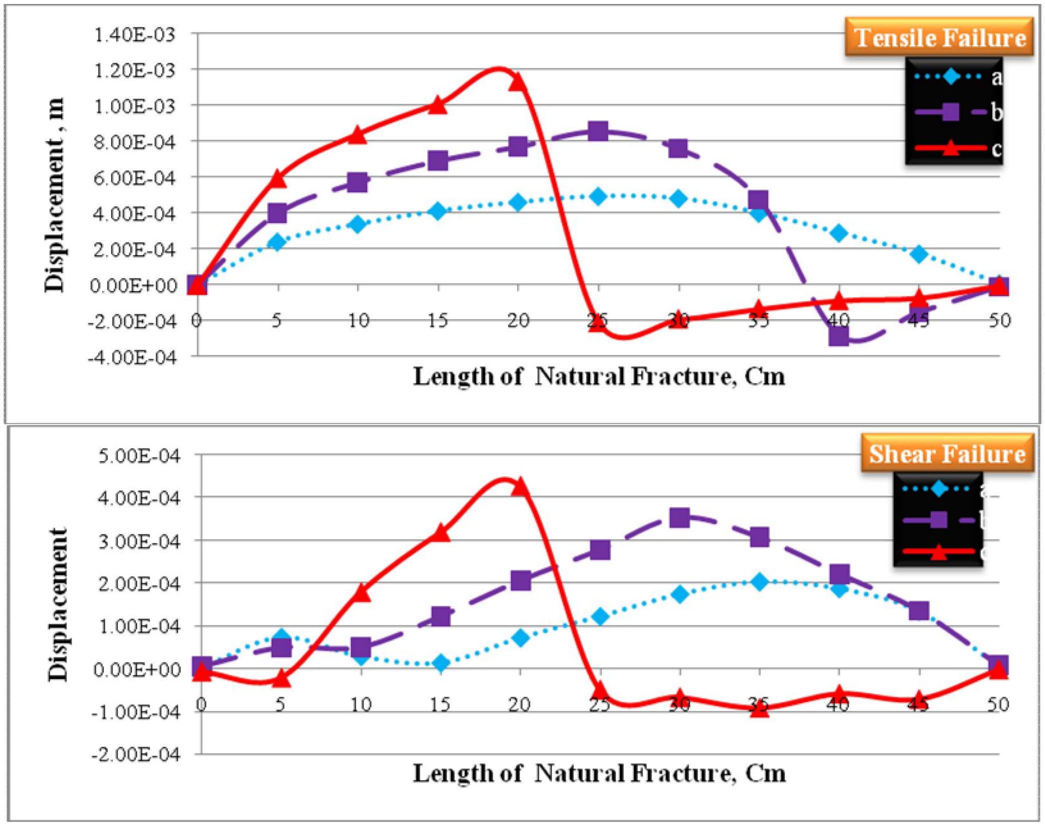


Figure11. Opening and sliding displacements along the debonded zone of Figure 10

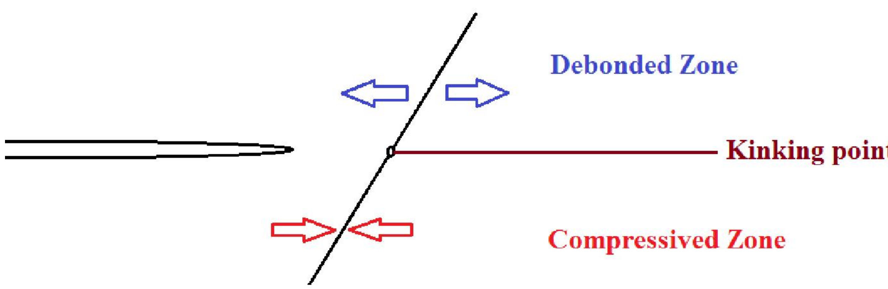


Figure12. Schematic illustration for debonding induced by the approaching crack

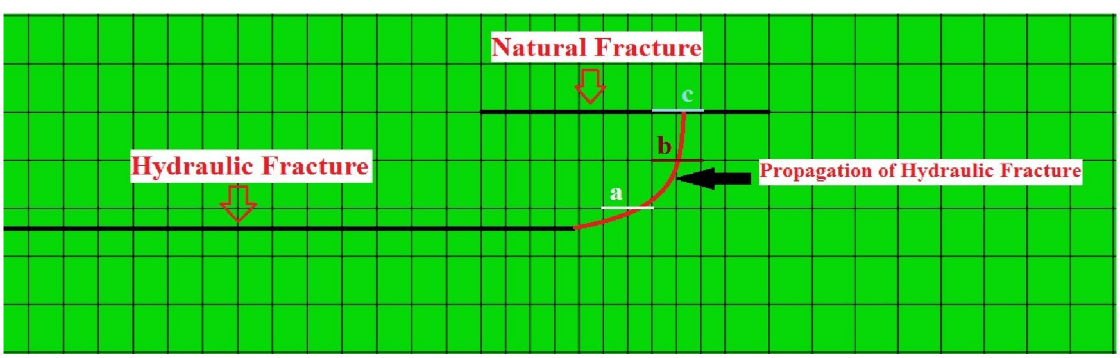


Figure13. Areas of study for natural fracture Debond when the induced fracture with zero-degree angle relative to natural fracture expands

We are here to connect the hydraulic fracture to natural fracture under the terms of isotropic tried different distances in order to induce these two together and we reached this conclusion that under these conditions when relativity of the vertical distance between natural fracture and induced fracture to natural fracture length become 0.5 the coalescence will occur. Thus the vertical distance of 25 cm fracture Coalescence occurred. However under anisotropic condition, and depending on the difference between the maximum and minimum of horizontal principal stress, the situation will quite different. Graphs of shear and tensile failure when natural and induced fractures become zero degree angles compared together are shown in figure 14.

In tensile failure subject, when induced fracture reached regions a and b, a debonding phenomenon more inclined to the right side of natural fracture. In other words when hydraulic fracture is located in region a, at the tip of a hydraulic fracture is located approximately in the middle of the natural fracture so the tensile debonding is almost symmetric mode and the maximum amount of tensile debonding in the middle of natural fracture. But by reach the region b, fracture tip is not in the middle of the natural fracture, so due to fracture coalescence phenomenon to be tends and slightly is deflected to the right so that the tensile debonding that occurs in the area b in right side is more but the remarkable thing is that the maximum amount of tensile debonding is in the center of natural fracture but by cutting the natural fracture by induced fracture (area c) the maximum amount of tensile debonding occurs in kink point. With cutting of natural fracture, as well as tensile debonding status changes, so that part of the kink point that located on the right side opens but the left side is suffering from congestion or closure just like the same phenomenon that happened in the 45 degree. It is important to note here that the concentration is not too high.

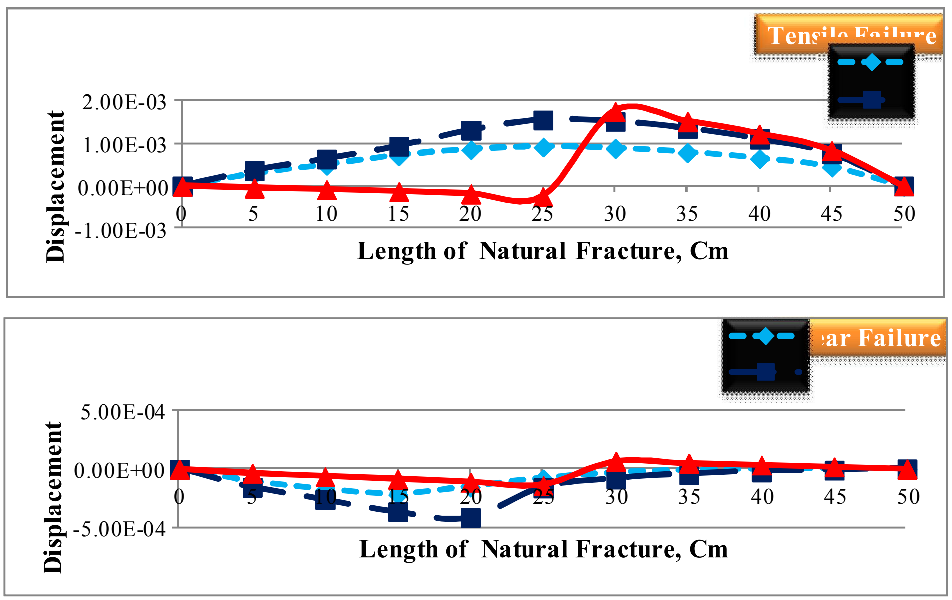


Figure 14. Opening and sliding displacements along the debonded zone of Figure 13

In the shear failure part, note that before cutting natural fracture the shear debonding in all over of fracture has the same direction. With reach the induction fracture to region a, the highest rate of shear debonding is in the left side of natural fracture on a 15 cm of natural fracture from left to right (In the b region). Here we have same situation as was in a area however, the rate of shear debonding is more and more inclined to the right side And the maximum amount of shear debonding is at 25 cm natural fracture from left to right. With cutting of natural fracture shear debonding has not same direction is all over the fracture, and it is positive in right side and negative on the other side. The main important point is that in the kink point we have directions change and the intersection point of shear debonding at both sides of fracture is located at same point.

Conclusion

Analysis of length and height of hydraulic fracture on production rate and interaction between natural and induced fracture in the fractured reservoir were studied in this study.

As seen, in reservoir with high-density natural fracture, creating a hydraulic fracture with high conductivity is suitable and in an environment with low natural fractures that dispersion of the natural fracture is high (low density of natural fractures) a hydraulic fracture with high length will be much better. In reaction between natural and induced fractures depend on the angles that have these fractures we can reach a different condition. Here we examined three angles 90, 45 and zero degrees. As was observed in both tensile and shear debonding, which was itself based on these angles showed a different behavior.

The coalescence of the hydraulic fracture with open natural fractures causes strain relaxation at the reaching tip, which provides larger volumes mainly inside the primary hydraulic fracture and then the connected natural fracture.

Reference

1. Zhang, Z., and Ghassemi, A. 2011. Simulation of hydraulic fracture propagation near a natural fracture using virtual multidimensional internal bonds, International Journal for Numerical and Analytical Methods in Geomechanics 35(4):480-495.
2. Weng, X., Kresse, O., Cohen, C., Wu, R., and Gu, H. 2011. Modeling of Hydraulic Fracture Network Propagation in a Naturally Fractured Formation. Paper SPE 140253 presented at SPE hydraulic fracturing technology conference and exhibition. The Woodlands, Texas, USA, 24-26 January.
3. Ahmed H. Al-Huthali, Saudi Aramco and Akhil Datta-Gupta, 2004, Streamline Simulation of Water Injection in Naturally Fractured Reservoirs, presented at the 2004 SPE/DOE Fourteenth Symposium on Improved Oil Recovery held in Tulsa, Oklahoma, U.S.A., 17–21 April 2004.
4. Z. Zhao, SPE, D. Liu, W. Liu, L. Chai, and H.Zhou. 2005. Development of Systematic Hydraulic Fracturing Technology for a Naturally Fractured Reservoir. SPE 94101, Presented at the SPE Europec/EAGE Annual Conference held in Madrid, Spain, 13-16 June 2005.
5. Shum, D.K.M. and J. Hutchinson, 1990, on toughening by microcracks, mechanics of material, Vol.9, pages 83-91.
6. Hutchinson, J.W., 1987, Crack tip shielding by micro-cracking in brittle solids, Acta Metallurgica, Vol. 35, No. 7, pp.1605-1619.
7. Zhang, Z., and Ghassemi, A. 2011. Simulation of hydraulic fracture propagation near a natural fracture using virtual multidimensional internal bonds, International Journal for Numerical and Analytical Methods in Geomechanics 35(4):480-495.
8. Weng, X., Kresse, O., Cohen, C., Wu, R., and Gu, H. 2011. Modeling of Hydraulic Fracture Network Propagation in a Naturally Fractured Formation. Paper SPE 140253 presented at SPE hydraulic fracturing technology conference and exhibition. The Woodlands, Texas, USA, 24-26 January.
9. Fisher, M.K., C.A. Wright, B.M. Davidson, A.K. Goodwin, E.O. Fielder, W.s. Bucckler, and N.P. Steinsberger. 2005. Integrating Fracture- Mapping Technologies to Improve Stimulations in the Barnett Shale. SPE prod and Fac., 85-93.
10. Freund, L.B. 1990. Dynamic fracture mechanics, Cambridge University Press.
11. Talaghani, A.D: Analysis of hydraulic fracturing propagation of fractured reservoirs: an improved model for the interaction between induced and natural fracture, PhD Thesis, University of Texas at Austin (2009).

9/20/2012