Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 15, No. 1, 2025

Research Progress on Hydraulic Fracturing Test and Numerical Simulation of Fractured Reservoirs

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Abstract: Due to the influence of geological conditions, there are a large number of natural fractures or cleats distributed in the reservoir, which directly affect the effect of hydraulic fracturing. In order to clarify the mechanism of action between hydraulic fractures and natural fractures, the current research on hydraulic fracturing fracture propagation in fractured reservoirs is reviewed from two aspects of experiment and numerical simulation. Firstly, the research progress of experiment is introduced. Then, the related research of numerical simulation is expounded. Finally, the general conclusions of hydraulic fracturing in fractured reservoirs are summarized, and the future research is prospected.

Keywords: Fractured reservoir; natural fractures; hydraulic fracturing; test; numerical simulation.

1. Introduction

As an important technology for unconventional oil and gas exploitation, hydraulic fracturing has been developed for nearly 80 years since its inception in the 1940 s. It injects fluid into the target reservoir to exceed the amount of fluid that can be accommodated by its pore elasticity, so that the reservoir cracks, so as to achieve the purpose of mining unconventional oil and gas. With the development of unconventional oil and gas resources, under the guidance of China 's " dual carbon goal, " the transformation of energy structure is accelerating. Natural gas, as a link between traditional fossil energy and renewable resources, the importance of hydraulic fracturing technology is becoming increasingly prominent. At present, hydraulic fracturing has made remarkable progress in theory and practice. Due to the key role of hydraulic fracturing in unconventional oil and gas exploitation, it has always been a hot research field of oil and gas resource exploitation.

However, due to the influence of geological conditions, strong tectonic deformation and physical diagenesis in the reservoir, there are a large number of randomly distributed natural fractures or cleats in the reservoir[1-2].In the process of hydraulic fracturing, the expansion of hydraulic fractures must be affected by these fractures and cleats, thus affecting the fracturing effect. Therefore, it is very important to understand the expansion of hydraulic fractures in fractured reservoirs and the interaction mechanism between hydraulic fractures and natural fractures and cleats. It directly affects the formation of fracture networks and affects the production and migration path of gas.

In recent years, for fractured reservoirs, domestic and foreign scholars have carried out a lot of research on hydraulic fracturing from the aspects of test and numerical simulation. Hydraulic fracturing test is the most direct means to study fracture propagation, mainly through similar material test or true triaxial test of raw coal samples. The difference between the current experimental research is mainly due to the use of different loading methods, sample size, stress size, data monitoring methods and pump injection during fracturing. However, the test may be limited by excessive stress, difficulty in sampling or difficulty in loading, which may lead to unsatisfactory results.

Compared with the limited numerical simulation of experimental conditions, it has become an ideal means to study the hydraulic fracture propagation in fractured reservoirs. The classical numerical simulation method of hydraulic fracturing is based on the discontinuous displacement method to predict the fracture parameters of three classical parallel plate fracture models KGD, PKN and Radials[3-7]. The main simulation methods are finite element method, discrete element method, phase field method and lattice model.

From the perspective of engineering practice, as the fracturing process and fracturing parameters become more and more complex, the scale of fracturing becomes larger and larger, and the study of hydraulic fracturing fractures and the development of fracture networks become more important. This paper summarizes the current research progress of hydraulic fracturing from two aspects of experiment and numerical simulation, and introduces the research status of hydraulic fracturing in fractured reservoirs.

2. Hydraulic Fracturing Test Research Status

Heng et al.[8] used the indoor large-scale true triaxial hydraulic fracturing test system, and used the outcrop shale to process the fracturing sample with a size of 300mm × 300mm × 300m to carry out the hydraulic fracturing test with bedding. The hydraulic fracture expands along the parallel bedding direction and the approximate vertical bedding direction at the wellbore, which illustrates the influence of fracture toughness on the fracture propagation. The hydraulic fracture encounters the bedding surface with small fracture toughness during the propagation. It will turn and bifurcate, further communicate the natural fractures to form a complex fracture network and form volume fracturing.

Ma et al.[9] used hydraulic fracturing test system to study the propagation characteristics of hydraulic fractures in natural fractured reservoirs using similar material samples of prefabricated fractures, and used clear water with dye as fracturing fluid to observe fracture morphology. The sample size is 200 mm × 200 mm × 200 m cube, and the ratio is cement : gypsum : pulverized coal : water = 2 : 1 : 1 : 2, and the ratio is obtained by mechanical property test. The test results show that in the samples with prefabricated vertical fractures, the expansion of hydraulic fractures presents three expansion modes due to the presence of natural fractures. It stops at natural fractures, expands along natural fractures, extends to the tip of natural fractures, and then expands. The pump pressure curves and fracture expansion of different samples are different, indicating that the mechanical properties of the reservoir will affect the fracturing effect. In the specimens with prefabricated horizontal fractures, the results are different from those of prefabricated vertical fractures, indicating that the location of natural fractures also affects the fracturing effect.

Zhou et al.[10] studied the influence of natural fractures on the propagation behavior and geometry of hydraulic fractures in fractured reservoirs through a triaxial fracturing test system (Fig.1).In the fracturing process, the effects of horizontal stress field, approaching angle and shear strength of prefabricated natural fractures on the propagation of hydraulic fractures were considered. The results show that the higher the shear strength of the prefabricated natural fracture, the more easily the hydraulic fracture propagation is prevented by the natural fracture. The shape of the hydraulic fracture in the reservoir with natural fracture is mainly controlled by the in-situ stress and the natural fracture approaching angle. When the hydraulic fracture encounters the natural fracture, it is possible to offset and produce bending fracture.

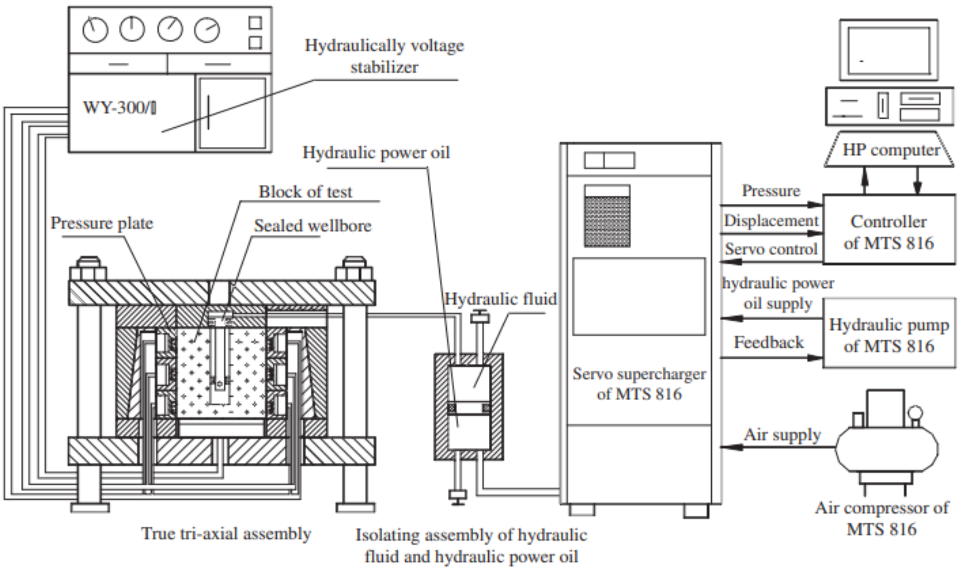


Figure 1. Triaxial fracturing test system diagram[10]

Zhang et al.[11] used the triaxial fracturing system monitored by acoustic emission to discuss the influence of closed cemented natural fractures on the propagation of hydraulic fractures in tight sandstone, and studied the influence of natural fractures in different directions on hydraulic fractures. The results show that when the angle between the natural fracture and the direction of the maximum principal stress is 30°-60°, the geometric shape of the hydraulic fracture is the most complex, and the number of activated natural fractures is the most, while the deflection conditions are different under other angles. There are four interaction modes between natural fractures and hydraulic fractures, namely, deflection along natural fractures, stopping after expansion along natural fractures, directly passing through natural fractures, and extending along natural fractures + directly passing through natural fractures.

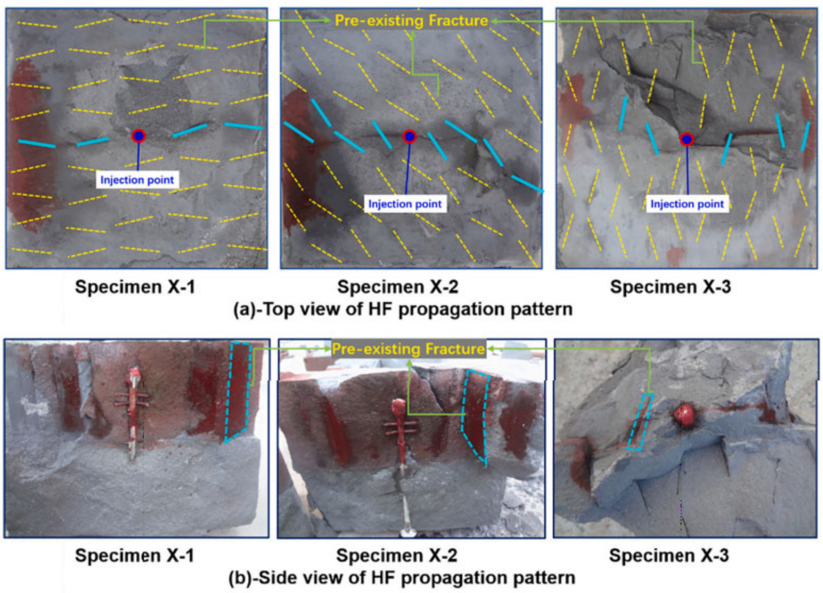


Figure 2. Fracture morphology[11]

Jiang et al.[12] used the self-developed multi-functional fluid-solid coupling true triaxial test system, based on the theory of tensile fracture induced by stress concentration on the hole wall, and combined with fracture mechanics to study the fracture propagation law of hydraulic fracturing coal. The results show that natural fractures will induce hydraulic fractures to expand along natural fractures, which can reduce the initiation pressure, and the initiation pressure is the smallest when natural fractures are perpendicular to the minimum principal stress.

3. Numerical Simulation of Hydraulic Fracturing in Fractured Reservoir

Zhu et al.[13] established a seepage-stress-damage coupled finite element-discrete fracture network model to study fracture propagation, and verified the correctness of the model by using the analytical solution of the KGD model. The effects of natural fracture approximation angle, cluster spacing, horizontal stress difference and displacement on fracture propagation were studied. The results show that the larger the approaching angle is, the more easily the hydraulic fracture propagation is affected by natural fractures, or even blocked, resulting in shorter fracture length. The larger the cluster spacing is, the weaker the inhibition of crack propagation is ; the increase of flow rate will not change the mechanism between natural fractures and hydraulic fractures. The final results show that there are three main mechanisms between hydraulic fractures and natural fractures : passing through natural fractures, opening natural fractures and being prevented by natural fractures.

Li et al.[14] used the finite element RFPA2D-Flow software to study the influence of natural fracture filling, stress difference and the angle between natural fracture and hydraulic fracture on the propagation of hydraulic fracture. It is considered that there are three modes of crossing, turning and migration when hydraulic fracture and natural fracture meet.

Wasantha et al.[15] used two-dimensional discrete element method to study the geometric shape of hydraulic fractures with or without natural fractures in the reservoir. It was found that natural fractures have a significant effect on the symmetry of hydraulic fractures. The stiffness of natural fractures, the approaching angle, and the distance between the wellbore and natural fractures will affect the propagation of hydraulic fractures. It is considered that the asymmetry of hydraulic fracture propagation can be reduced by increasing the stiffness and approaching angle of natural fractures, and the influence of natural fractures more than 50 m away from wellbore on hydraulic fracture propagation can be neglected. It is found that it is difficult to further expand after the intersection of hydraulic fractures and natural fractures.

Based on the discrete fracture network model, Li et al.[16] established a three-dimensional model and used the displacement discontinuity method to simulate the expansion of hydraulic fractures in fractured reservoirs and the interaction between hydraulic fractures and natural fractures. The results show that the strong interaction between hydraulic fractures and natural fractures makes the fracture network complex. The increase of liquid injection displacement can increase the complexity of fractures, and the complexity of fractures in the horizontal direction is less than that in the vertical direction.

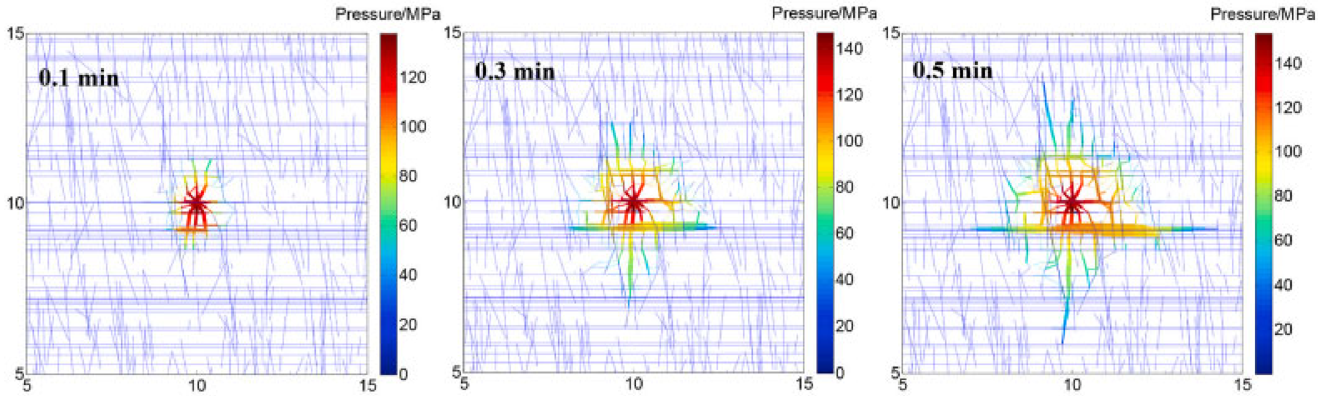


Figure 3. Hydraulic fracture propagation process[16]

Zhang et al.[17] used the continuous-discontinuous element method to establish the model, and discussed the mechanism of hydraulic fracture propagation and the influence of natural fracture characteristics on hydraulic fracture propagation. The results show that when the hydraulic fracture is close to the natural fracture, the natural fracture preferentially occurs shear failure, and the propagation speed of the hydraulic fracture slows down. When the natural fracture density is high, the hydraulic fracture is more likely to activate the natural fracture to form a curved fracture morphology, but it is not the higher the natural fracture density, the higher the degree of fracture. The length of the natural fracture also affects the scope of the fracturing, but it has little effect on the fracturing effect.

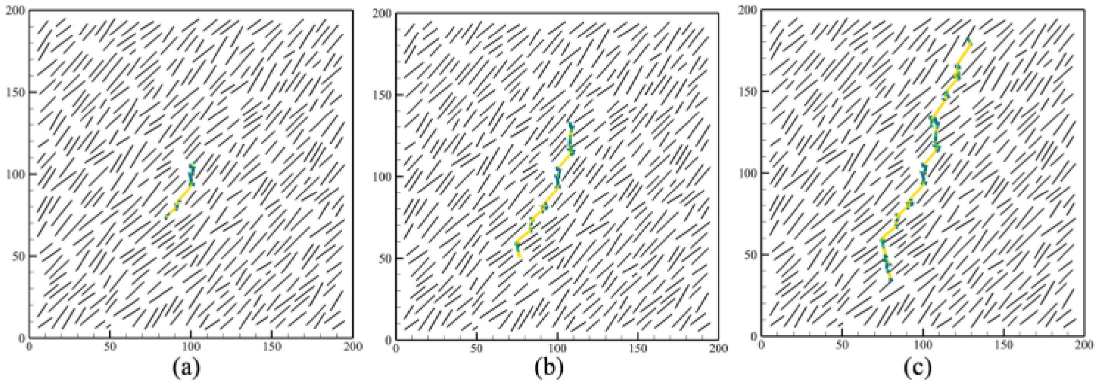
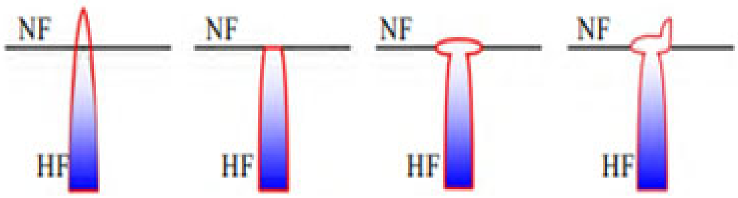


Figure 4. Fractured reservoir fracturing process[17]

4. Conclusion and Prospect

At present, great progress has been made in the experimental and numerical simulation of reservoirs with natural fractures. However, with the adjustment of the world energy structure, how to develop efficiently remains to be solved. This paper reviews some research progress in samples and numerical simulation of reservoirs with natural fractures. It is found that there are four main mechanisms of interaction between hydraulic fractures and natural fractures, namely, hydraulic fractures directly pass through natural fractures, hydraulic fractures are captured by natural fractures (natural fractures prevent the expansion of hydraulic fractures), hydraulic fractures turn to expand along natural fractures, hydraulic fractures first expand along natural fractures and then turn to the direction of maximum principal stress, as shown in Figure 5.



(a)pass-through (b)capture (c)diversion (d)offset

Figure 5. Interaction mechanism between hydraulic fracture and natural fracture[18]

At present, most of the natural fracture tests carried out have fewer prefabricated natural fractures, and cannot show the impact of the density of natural fractures contained in real reservoirs. The numerical simulation is mostly two-dimensional model to study the role of hydraulic fractures and natural fractures, ignoring the possibility of other forms of expansion in the real three-dimensional case. Therefore, the next step is to carry out three-dimensional simulation work consistent with the test and simulation, which can further discover new results, increase the reliability of data, and lay the foundation for increasing the fracturing effect.

References

[1] Yue F, Jiao W W, Guo S J. Controlling factors of fracture distribution of shale in Lower Cambrian Niutitang Formation in southeast Chongqing [J]. Coal Geology & Exploration, 2015, 43(06):39-44.(in Chinese)

[2] Hao X J, Yang H X, Zhang T, et al. Effect of natural fracture and confining pressure on damage dilatancy point of deep coal measures reservoir and acoustic emission identification [J]. Journal of China University of Mining& Technology, 2023, 52(04):648-659. (in Chinese)

[3] Perkins TK, Kern LR. Widths of hydraulic fractures[J]. Journal of Petroleum Technology, 1961, 13(9): 937-949.

[4] Nordren RP. Propagation of a vertical hydraulic fracture[J]. Society of Petroleum Engineers Journal, 1972, 12(8): 306-314.

[5] Khristianovic SA, Zheltov YP. Formation of vertical fractures by means of highly viscous liquid[M]. In: Proceedings of the fourth world petroleum congress, 1995, 79-86.

[6] Greertsma J, de Klerk F. A rapid method of predicting width and extent of hydraulically induced fractures[J]. Journal of Petroleum Technology, 1969, 21: 71-81.

[7] Abe H, Mura T, Keer LM. Growth-rate of a penny-shaped crack in hydraulic fracturing of rocks [J]. Journal of Geophysical Research, 1976, 81(29): 35-40.

[8] Heng S, Yang C H, Guo Y T, et al. Influence of bedding planes on hydraulic fracture propagation in shale formations [J]. Chinese Journal of Rock Mechanics and Engineering, 2015, 34(02):228-237. (in Chinese)

[9] Ma G, Zhang F, Liu X, et al. Experimental study on hydraulic fracture propagation in fractured reservoir[J]. Journal of Mining & Safety Engineering, 2017, 34(05):993-999.

[10] Zhou J,Chen M,Jin Y,et al. Analysis of fracture propagation behavior and fracture geometry using a tri-axial fracturing system in naturally fractured reservoirs[J]. International Journal of Rock Mechanics and Mining Sciences, 2008, 45(7):1143-1152.

[11] Zhang J, Li Y W, Pan Y S, et al. Experiments and analysis on the influence of multiple closed cemented natural fractures on hydraulic fracture propagation in a tight sandstone reservoir [J]. Engineering Geology, 2021, 281: 105 981.

[12] Jiang C B, Yang Y H, Liu H H, et al. Study on the influence of natural fractures on the initiation and propagation of hydraulic fracturing coal [J]. Coal Science and Technology, 2024, 52(05):92-101. (in Chinese)

[13] Zhu H Y, Huang C H, Tang X H. Numerical simulation of multi-cluster fractures propagation in naturally fractured shale reservoir based on finite element method-discrete fracture network[J]. Chinese Journal of Rock Mechanics and Engineering, 2023, 42(S1):3496-3507. (in Chinese)

[14] Li W, Tang C A, Li L C. Numerical Simulation Research on the Perturbation Mechanism of Simultaneous Fracturing in Jointed Rock Masses[J]. Chinese Journal of Underground Space and Engineering, 2018, 14(03):719-728. (in Chinese)

[15] Wasantha P.L.P, Konietzky H, Weber F, et al.Geometric nature of hydraulic fracture propagation in naturally-fractured reservoirs[J].Computers and Geotechnics,2017,83:209-220.

[16] Li Y Y, Hu W, Zhang Z H, et al. Numerical simulation of hydraulic fracturing process in a naturally fractured reservoir based on a discrete fracture network model[J]. Journal of Structural Geology, 2021, 147:104331.

[17] Zhang B, Guo T K, Chen M, et al. Research on fracture propagation of hydraulic fracturing in a fractured shale reservoir using a novel CDEM-based coupled HM model[J].Computers and Geotechnics, 2024,168:106170.

[18] Yang D S, Zhou Y, Zhou Z L. A review of experimental and numerical simulation of hydraulic fracturing in reservoirs with interfaces[J]. Chinese Journal of Rock Mechanics and Engineering, 2022, 41(09):1771-1794. (in Chinese)