Experimental study of fracture propagation in glutenite reservoir influenced by oriented perforation design

Mingzhong Li [1, a], Shukai Tang [1, b], Shuo Zhang [1, c], Tong Li [2, d]

[1]School of petroleum engineering, China University of Petroleum (East China), Qingdao 266580, Shandong, China;

[2] The third oil production plant, PetroChina Huabei Oilfield Company, Cangzhou 062450, Hebei, China.

[a]limingzhong_upc@hotmail.com, [b]kennytown@139.com, [c]linyiqiong1@163.com, [d]407169877@qq.com

Abstract

The characteristics of the large buried depth, the large thickness and the severe heterogeneity of the glutenite reservoir bring many difficulties for hydraulic fracturing design and site operation, especially for the existence of gravel which results in the formation of fracture morphology of hydraulic fracturing difficult to control. The oriented perforating technology is applied to the fracturing process of the glutenite reservoir, which makes full use of the stress concentration effect at the perforation tip to change the cracking initiation point of hydraulic fracture and avoid the influence of reservoir gravel near wellbore area on the fracture initiation, thus achieving better fracturing effect. The effect of the oriented perforation parameters and gravel distribution on the fracture initiation and expansion form of hydraulic fracturing fracture was studied with the experiment on seven groups of rock samples artificially prepared by using the true triaxial hydraulic fracturing system. The experimental results show that the oriented perforation can effectively change the cracking initiation point of hydraulic fracture. Under the guidance of the oriented perforation, new fractures will all deviate from the direction of maximal principal stress and form turnaround fractures. Compared to the perforation depth, the perforation density has a greater impact on the steering condition of the fractures; when the azimuth angle of perforation is 45 degrees, the cracking initiation point is at the perforation tip, but it returns to the direction of maximal principal stress when it expands.

Keywords

Fracture propagation, glutenite reservoir, oriented perforation.

1. Introduction

The need to adapt to the situation

The glutenite reservoir has the characteristics of low porosity, low permeability, deep burial depth, high formation temperature, large thickness variation, complex lithology, natural fracture development and severe heterogeneity, which results in low natural productivity of single well in the development process, thus hydraulic fracturing is required to achieve its economic and effective development [1-4]. In the hydraulic fracturing process of the glutenite reservoir, the existence of gravel affects the expansion trajectory of original fractures and creates more complex fractures which deviate further from the direction of maximal principal stress. The application of the oriented perforating technology in the hydraulic fracturing process of glutenite reservoir can effectively reduce the impact of the gravel on the fracture initiation to achieve better hydraulic fracturing effect.

The traditional application of the oriented perforating is to launch the perforating bullet along the direction of maximal horizontal principal stress by controlling the perforation tunnel direction, thus forming a more flat single hydraulic fracture with larger height. In the aspects of the mechanism of turnaround fracture propagation under oriented perforation, Daneshy [5] et al. studied the effects of the perforation density, the perforation azimuth, the diameter of perforation hole and other factors on hydraulic fracturing pressure, and found that the density and the azimuth have a greater impact on the fracturing pressure. Ketterij [6] et al. conducted reduced-scale experiments and established a pressure calculation model near the wellbore. Based on this model, the effects of the perforation angle on formation stress distribution and fracture propagation were analyzed. Zhang [7] et al. established a three-dimensional finite element model to study the influence of oriented perforation parameters on the hydraulic fracture propagation shapes. The results show that the interference phenomenon between adjacent perforations will affect the hydraulic fracture initiation guided by oriented perforation, while the angle between the perforating direction and the maximal principal stress direction as well as the horizontal stress difference will affect the fracture shapes. In addition, many scholars have studied the guiding effect of oriented perforation on hydraulic fracture propagation by using theoretical models and experiments, and obtained many beneficial conclusions [8-16]. However, previous studies on fractures guided by oriented perforation in glutenite reservoirs or rock samples are limited, which cannot provide guidance for site operation design.

This paper studies the effect of oriented perforation on the initiation and extension of hydraulic fracture in glutenite reservoir through experiments. Seven glutenite rock sample with oriented perforation were artificially prepared in laboratory and tested in large-size true triaxial hydraulic fracturing experimental equipment. We studied the effects of principal stress difference, perforation depth, perforation density and azimuth angle on the initiation and propagation of hydraulic fractures, and analyzed the effects of gravel on the fracture propagation which can guide the design of the site hydraulic fracturing operation.

2. Hydraulic fracturing experiment of glutenite sample guided by oriented perforation

2.1 Glutenite sample preparation with oriented perforation

In the process of site operation, the frequently used borehole diameter is 200-400mm, perforation depth is 500-1000mm, perforation density is 12 hole/m, 16 hole/m, 20 hole/m, 32 hole/m. It is impossible to make the model of the original size to simulate the rule of fracture propagation in the laboratory. Therefore, we needs to design a 1:10 scale model by using similar theories in the experiment. The experimental parameters are shown in Table 1.

Table 1 Sample size parameter

test-piece size mm	300×300×300
Simulated borehole diameter mm	25
Simulated perforation diameter mm	5 mm×6；2 mm×1
Simulated perforation length cm	9
Simulated perforation density（conversion）	32hole/m；12hole/m

In order to simulate the vertical well, the straight pipe is machined and cut to shape according to the size of design with one end plugged which is embedded in the mortar as the bottom and the other end connecting thread as the top. The design drawing is shown in Fig. 1.

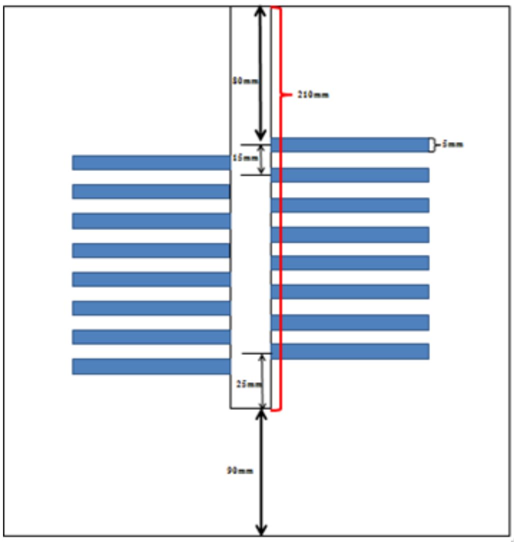

Fig. 1 Design of the simulated perforation wellbore

The method of reserving perforation location is employed in perforation simulation. The perforation phase angle is 180 degrees and the arrangement of holes is in a simple planar way. The perforation is distributed in the center of the test-piece at 10 cm. Each hole is drilled with a 5 (2)-mm-diameter drilling bit. The steel pipe rotates a phase of 180 degrees according to the design angle every time one hole is drilled, and at the same time the steel pipe moves forward corresponding distance (0.75 cm, 2.5 cm). Then a hole is drilled and the cycle continues until the end. The PTFE tube is installed on the hole where the perforation is needed. The PTFE tube is installed at the specified location according to different experimental requirements.

The raw materials for the test-piece preparation are cement, water, sand and gravel (different shapes and sizes, the proportioning obtained according to the core data), additives etc. According to the rock mechanical characteristics of the cores taken from Yongan glutenite block in Shengli Oilfield, the mortar proportioning of rock samples is determined as shown in Table 2.

Table2 Mortar mix ratio (mass ratio)

Cement 325#	sand	gravel	Water reducer	water(water contained in water reducer not taken into consideration)
0.5	2.5	1	0.004	0.5

2.2 Experimental facility

The main equipment used in this experiment is servo-controlled triaxial experimental system for rock mechanics. The experimental system is mainly composed of hydro-power pump package, triaxial stress loading system and main control computer. The equipment structure composition is shown in Figure 2. The control system of the experimental equipment adopts fully digital controller with high control precision and high reliability.

The main parameters of the equipment are: 80 cm internal diameter of the high pressure cylinder, working pressure of 30-40MPa; the triaxial proportional servo of the power pump, power of 10kw.

2.3 Experimental schemes and procedures

In order to ensure the preciseness and accuracy of the research, laboratory simulated experiments of hydraulic fracturing were conducted by combining the conditions of different perforation density, hole diameter, hole depth and in-situ stress to obtain the rule of fracture propagation and extension under different conditions, thus optimizing perforation parameters.

Fig.2 Hydraulic fracturing experimental device

Table3 Experimental scheme of perforation induced wellbore fracture extension

Core number	Hole number	in-situ stress /MPa	azimuth	Perforation diameter /mm	Perforation depth/cm	Perforation density /(hole/m)	lithology
1#	left and right vertically 8 holes	20/15/13	90°	5	9	32	glutenite
2#	left and right vertically 8 holes	20/15/10	90°	5	9	32	glutenite
3#	left and right vertically 3 holes	20/15/13	90°	5	9	12	glutenite
4#	left and right vertically 8 holes	20/15/10	45°	5	9	32	glutenite
5#	left and right vertically 8 holes	20/15/13	90°	2	9	32	glutenite
6#	left and right vertically 8 holes	20/15/13	90°	5	3	32	glutenite
7#	left and right vertically 8 holes	20/15/13	90°	5	9	32	Conventional fine sandstone

The experimental steps are as follows:

①Mark and take pictures of the test rock samples which have been made, and then pour the fracturing fluid into the wellbore (clear water mixed with red ink for easy observation of the experimental results) and put it into the test device.

②Apply three-dimensional stress to the sealed simulated wellbore gradually until the ratings, which is pressurized by the oil pump, and this operation must be synchronized with the pressure application to ensure the uniform stress of rock samples.

③After the confining pressure reaches the test requirement, keep the pressure unchanged and inject water to fracture by the constant flow-rate pump.

④Observe the changing curve of pressure vs. time and make records properly.

⑤After the experiment, first empty the pressure of the constant flow-rate pump, then slowly reduce the confining pressure, finally open the top-pressure cap to observe the fracture morphology of the sample after fracturing and take photos.

⑥Take out the sample, connect the constant flow-rate pump, inject water without confining pressure and stop the pump after the liquid seeping on the surface of the test-piece in order to break through the fracture and observe the shapes.

⑦Clean the wellbore and repeat the steps above to test the next sample.

3. Experimental results and analysis

This experiment reflects the characteristics of in-situ stress of different reservoirs by controlling the stress difference, and at the same time changes the perforation parameters of each test-piece, including the perforation density, the hole depth and the hole diameter, to observe its guiding effect on new fractures.

As a basic experimental group of 1# test-piece, the principal stress difference is set to be 2MPa. The experimental results of hydraulic-fracturing true triaxial test show that 1# test-piece overcomes the effect of smaller horizontal principal stress difference under the guidance of oriented perforation. The hydraulic fractures initiate along the direction of perforation, i.e. the direction of minimal principal stress.

Fig. 3 is a section of 1 # test-piece, from which we can see the influence of gravel on the direction of fracture extension. Comparing to the relatively smooth and flat fracture surface of 7# core, both gravel-piercing and gravel-winding phenomena occur on the fracture section. Under the influence of the gravel, the left side of the wellbore in the figure develops gravel-winding-turning fractures.

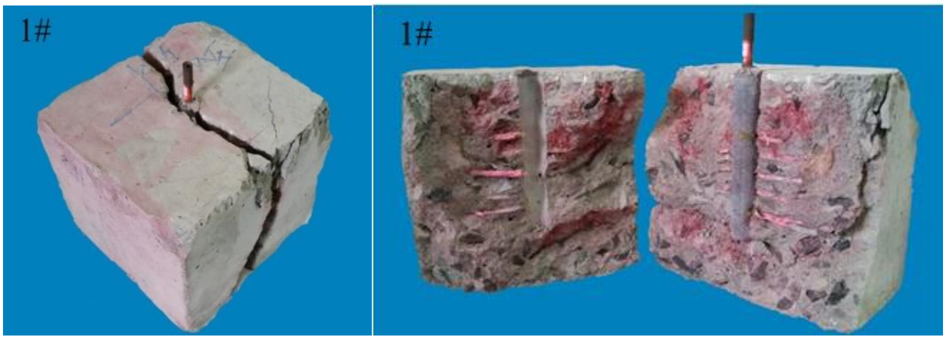

Fig.3 Experiment result of test-piece 1

2# test-piece simulates the effects of oriented perforation on fracture propagation process under the influence of conventional reservoir in-situ stress difference. As can be seen in Fig. 4, the fracture initiation point is near the perforating root due to the larger difference of principal stress and then the fracture tends to expand along the direction of maximal principal stress. The experimental results show that it is difficult for the samples with larger principal stress difference to form fractures along the direction of perforation.

Fig.4 Experiment result of test-piece 1

3# test-piece (Fig. 5) studied the fracture propagation when the hole is more sparse. It can be seen that when the perforation density is smaller, the fractures do not expand along the direction of maximal principal stress or the direction of perforation, but expand in the direction of inclined 45 degrees. The experimental results reflect the effects of the perforation density on the extension of fractures guided by perforation.

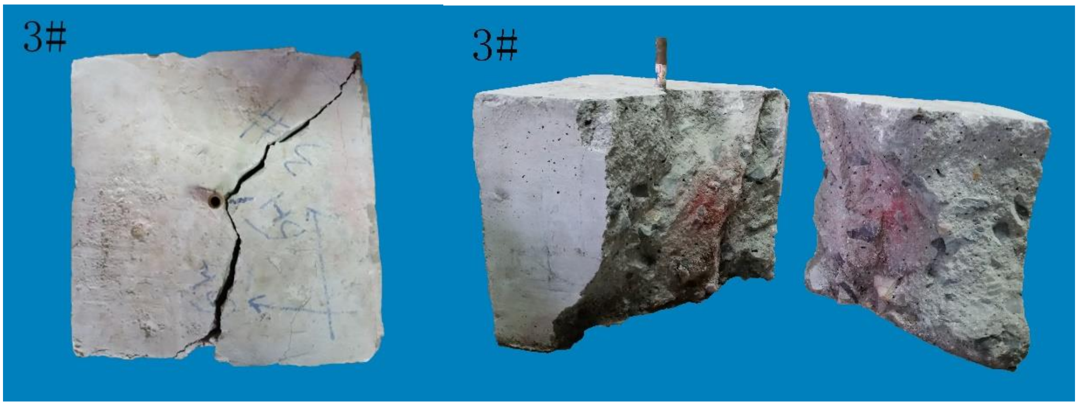

Fig.5 Experiment result of test-piece 3

The direction of perforation of the 4 # test-piece (Fig. 6) is inclined 45 degree. The fracture shape is as follows: Firstly, the fracture extends a distance along the direction of perforation and then turns back to the direction of maximal principal stress. The experimental results show that the perforation azimuth will affect the fracture morphology, and perforation perpendicular to the direction of maximal principal stress is more beneficial to the formation of fractures with larger turning radius compared to other perforation azimuths.

Fig.6 Experiment result of test-piece 4

5# test-piece (Fig. 7) adopts smaller perforation radius. The experimental results show that when the perforation diameter is smaller, it is difficult to build the pressure at the perforation location and the test-piece ruptures along the direction of the maximal principal stress. Therefore, it can be seen that smaller perforation diameter is unfavorable to guide turnaround fractures.

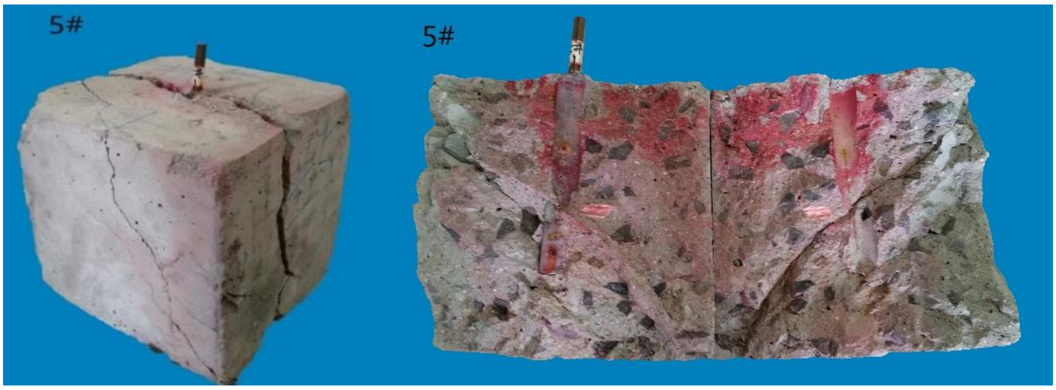

Fig.7 Experiment result of test-piece 5

6# test-piece (Fig. 8) studies the influence of different perforation depth on the direction of fractures. It can be seen from the picture that under the effect of shorter perforation radius, the fractures still initiate along the direction of perforation, forming a relatively more straight hydraulic fracture extending along the direction of minimal principal stress.

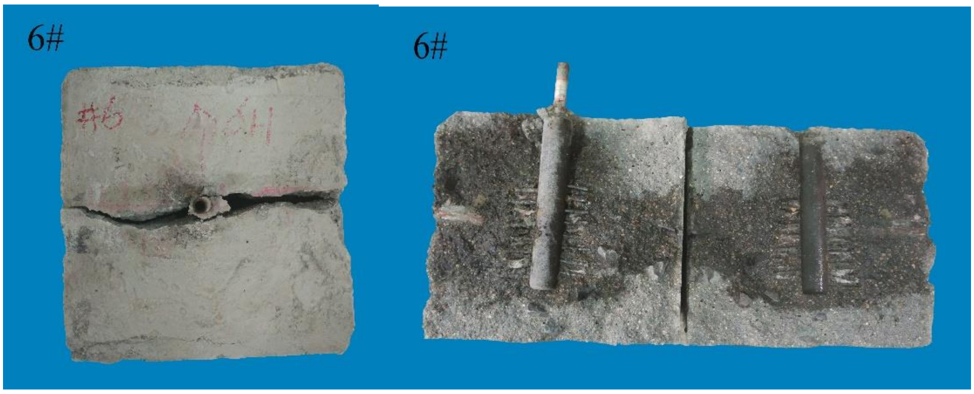

Fig.8 Experiment result of test-piece 6

Among the seven rock samples designed in the experiment, the fractures of 2# with larger principal stress difference and 5# with smaller perforation diameter initiate along the direction of the maximal principal stress. The 3# with more sparse hole and the 4# with perforation angle of 45 degree show the characteristics of turning, while the other rock samples fracture along the direction of perforation. Through the analysis of experimental results, it can be seen that reasonable design of oriented perforation can effectively guide the formation of turnaround fractures near the wellbore in reservoirs with relatively smaller stress difference.

The influence of gravel on fracture propagation morphology is mainly reflected in the complexity of it. From the comparison of Fig. 5-10 and the experimental results of 1# (glutenite rock sample) and 7# (sandstone sample), the fracture profile of 7# sandstone sample is obviously smoother than that of glutenite rock sample containing gravel.

From the section of 1# rock sample, there are both gravel-piercing and gravel-winding phenomena of fractures. From the side of the rock sample, it can be seen that the fracture surface formed by 1# rock sample shows a inclined slope of about 60 degrees, while the fracture surface of 7# rock sample is relatively flat. From the overhead view of 1# rock sample near the wellbore on the right side it can also be seen the fracture turning caused by gravel.

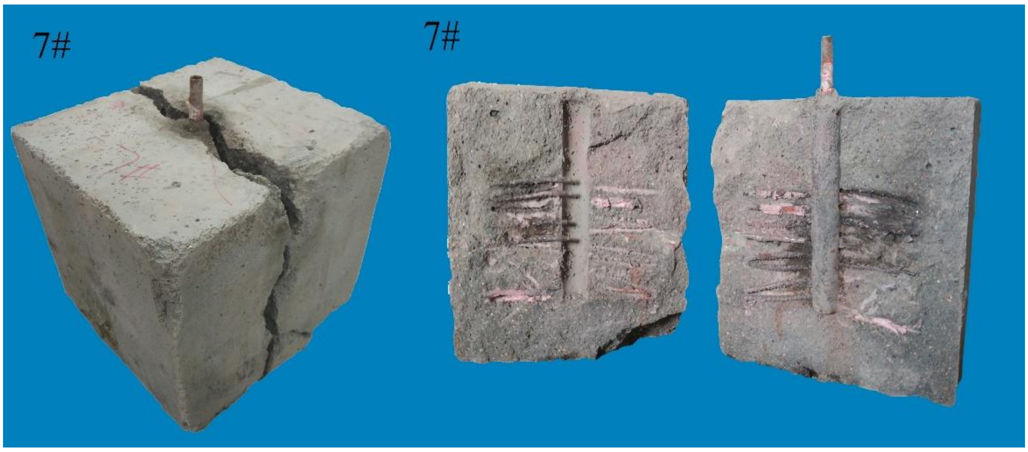

Fig.9 Experiment result of test-piece 7

From the experimental results above, it can be seen that the fracture formed by hydraulic fracturing in glutenite reservoir has the characteristics that the fracture surface is less flat, easy to happen steering and the morphology is more complex comparing to that of conventional sandstone reservoir. The reason is that the gravel with higher strength relative to the matrix acts as a resistance to the fracture tip in the path of fracture propagation which makes it difficult to form straight hydraulic fractures in glutenite reservoirs.

4. Conclusion

Through the experimental study of hydraulic fracture propagation of glutenite sample guided by oriented perforation, the conclusions are as follows:

(1) The experimental results show that oriented perforation plays a guiding role in fracture propagation. The fracture initiation points of four groups of test-pieces are located at the perforation tip, and the fractures generated basically deviate from the set direction of maximal principal stress. Therefore, reasonable design of oriented perforation can effectively guide the formation of turnaround fractures in reservoirs with relatively small stress difference.

(2) Compared to the perforation depth, perforation density has a greater impact on the condition of fracture steering; when the perforation azimuth is 45 degrees, the initiation point is at the perforation tip, but it returns to the direction of maximal principal stress when it expands.

(3) Compared to the glutenite sample, the fracture surface formed by the conventional sandstone sample is smoother and flatter, the diversion is smaller, and the extension pressure of hydraulic fracture is relatively lower.

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