11-2018

# Study on the mechanisms of refracturing technology featuring temporary plug for fracturing fluid diversion in tight sandstone reservoirs

Wei Li

Huan Zhao

Hui Pu
*University of North Dakota*, hui.pu@UND.edu

Yuguang Zhang

Lei Wang

***See next page for additional authors***

**Authors**
Wei Li, Huan Zhao, Hui Pu, Yuguang Zhang, Lei Wang, Ligang Zhang, and Xiaofeng Sun

Received: 7 March 2018 | Revised: 17 October 2018 | Accepted: 26 October 2018

DOI: 10.1002/ese3.259

RESEARCH ARTICLE

Energy Science & Engineering Open Access

# Study on the mechanisms of refracturing technology featuring temporary plug for fracturing fluid diversion in tight sandstone reservoirs

**Wei Li**[1] | **Huan Zhao**[1] | **Hui Pu**[2] | **Yuguang Zhang**[3] | **Lei Wang**[3] | **Ligang Zhang**[1] | **Xiaofeng Sun**[1]

[1]College of Petroleum Engineering, Northeast Petroleum University, Daqing, China

[2]Department of Petroleum Engineering, University of North Dakota, Grand Forks, North Dakota

[3]Daqing Oilfield Production Technology Institute, Daqing, China

**Correspondence**
Huan Zhao, College of Petroleum Engineering, Northeast Petroleum University, Daqing, China.
Email: zhaohuan7696@163.com

**Funding information**
National Natural Science Foundation of China, Grant/Award Number: 51490650, 51774093 and 51704074

**Abstract**

Well production rates in unconventional plays usually decline dramatically in the first year. Refracturing, which is a remedial production operation, is often done because original hydraulic fracturing failed to contribute any significant amount of flow or significant unfractured pay exists in the well. In order to maximize the fracturing fluid contact with the intact rock and to stimulate more reservoir volume in previously stimulated wells, a refracturing technology featuring a novel temporary plugging for fluid diversion is developed to enable the fracturing fluid to reach the untouched areas and to create reoriented fractures. In this paper, laboratory physical simulation tests of refracturing using fiber for effective temporary plugging is carried out to study the refracture morphology and the influencing factors of refractures. Results show that the refracture morphology is affected by the horizontal stress difference, the injection rate of initial fracturing fluid, and the natural fractures. Under condition of the different horizontal stress differences, the fracture initiation and orientation angle are different. When the horizontal stress difference is small, it is easy to form large angle fractures. The injection rate of initial fracturing fluid affects the length of initial fractures and refractures. The smaller the initial fracturing fluid injection rate is, the better the effect of temporary plugging in refracturing. The presence of natural fractures will lead to reorientation of refractures to form a complex fracture network. This study provides a theoretical guidance and technology support for refracturing operations.

**KEYWORDS**

fracturing mechanisms, laboratory experimental study, refracturing, temporary plugging, treatment for hydraulic fractured wells

## 1 | INTRODUCTION

For the low and ultra-low permeability tight sandstone reservoirs, hydraulic fracturing technology can effectively improve the seepage characteristics of the reservoir and greatly enhance the oil and gas recovery of the reservoir. With the production of fractured wells, hydraulic fractures will gradually close, which will greatly affect the oil and gas production.[1] The refracturing technique has been proved to be an effective method for the well performance improvement of hydraulic fractured wells in the low and ultra-low permeability oilfields.[2] Laboratory experiments and field tests study by researchers in the world show that reoriented new refractures, which are different from the original fractures, can increase the recovery of oil and gas in tight sandstone reservoir.[3,4] The existing studies show that the fractures always initiate perpendicular to the minimum horizontal stress, and the distribution of the in-situ stress field in the reservoir determines the initiation and propagation of fractures.[5] Elbel developed a two-dimensional coupled model which showed that the stress difference at different positions varied with time and the original stress difference was the most important factor for the initiation of new fractures.[6] Wright suggested that the propagation of hydraulic fractures is controlled to a large extent by the in-situ stress field, where the initiation and propagation of fractures are reoriented when in-situ stress is reoriented.[7] Zhang studied the fracture propagation process of refracturing by both theoretical research and laboratory experimental simulation, and proposed a model of fracture propagation dynamics path in the process of fracturing; in the model, it was proposed that the horizontal stress difference and initiation angle are the critical factors influencing the refracture propagation.[8] Weng and Siebrits studied the effect of in-situ stress field changes caused by initial hydraulic fracturing on fracture propagation during refracturing by using PKN model with double fractures.[9] Siebrits argued that the in-situ stress field will change after the initial hydraulic fracturing, and the fracture initiation will start along the planes of different angles; the influential factors for the length and angle of refractures were studied by numerical simulation.[10] Peng Tan and Tiankui Guo studied the influences of multiple factors on fracture propagation and fracture morphology based on a series of physical experiments.[11,12] Song provided an innovative method to analyze time-dependent deformation of material at fracture tip and its effect on propagation of hydraulically induced fractures by incorporating visco-elastic behavior.[13] Taleghani studied the hydraulic fracture propagation in naturally fractured formation via numerical simulation and indicated the importance of nonlinear fracture tip effects as in-situ stress differences increase.[14] The acoustic emission was used to monitor the fracture behavior to elevated stress.[15] Based on the actual production of oilfield data, refracturing operations which only reopen the original fractures will not yield the desirable effect.[16] This is due to the fact that refracturing techniques tend to open the previous fractures, and thus only increase the conductivity of the original fractures, and do not increase the volumetric sweep area. On the other hand, refracturing tends to increase the length of the original fractures, which could lead to serious water channeling. In order to achieve an effective development of low permeability wells and stripper wells, and to avoid the reopening of previous fractures, refracturing treatments featuring temporary plugging agent-fiber for fracturing fluid diversion is widely used in oilfield.[17-19]

In order to study the influencing factors for refracture initiation mechanisms and fracture morphology in refracturing technology using temporary plugging for fluid diversion in tight sandstone reservoirs, we carried out large-scale true triaxial stress tests in condition of different horizontal stress differences and initial fracturing fluid injection rates. Acoustic emission experiments were also conducted to further study the characteristics of refracturing technology using temporary plugging for fluid diversion. The study provides a theoretical support and technical guidance for oilfield application of refracturing technology using temporary plugging for fluid diversion.

## 2 | MECHANISMS OF REFRACTURING USING TEMPORARY PLUGGING FOR DIVERSION

Daqing's peripheral oilfields have the characteristics of thin layer thickness, poor physical properties, poor oil-bearing potential, diverse reservoir lithology, and strong vertical heterogeneity. During the early phase of oilfield development in Daqing's peripheral oilfields, the effective measures to improve the production are water injection and hydraulic fracturing treatment. With the further development of oilfield, the effect of stimulation treatments deteriorated year by year. Conventional refracturing leads to reopen the initial fractures and it cannot increase the sweep area, and the improvement of well performance is hardly to be achieved. As stated in publications by Wright and Conant,[7] only by creating the new reoriented refractures, dead oil zone can be effectively produced. The mechanisms of refracturing using temporary plugging are shown in Figure 1.

The new reoriented refractures can be created by refracturing technique using temporary plugging for diversion. This refracturing technology is based on the theory of granular material blocking combined with hydraulic fracturing. The particles of temporary plugging agent, which are carried by fracture fluid, flow into the initial fractures or the high permeability layers. The temporary plugging agent can plug the high permeability area and raise the net pressure in the hydraulic fractures. The use of diverting agent strengthens the fracture pressure and achieves the fracture reorientation.[20,21]

As shown in Figure 2, when the initial fracture is half blocked, there is a certain length of unpropped fracture. This unpropped fracture will be closed under the effect of closing stress, but during the refracturing operations, the fractures will reopen, the effect of fracturing fluid plugging is stopped in the temporary plugged section of fracture. Temporary plugging agents accumulate in the initial

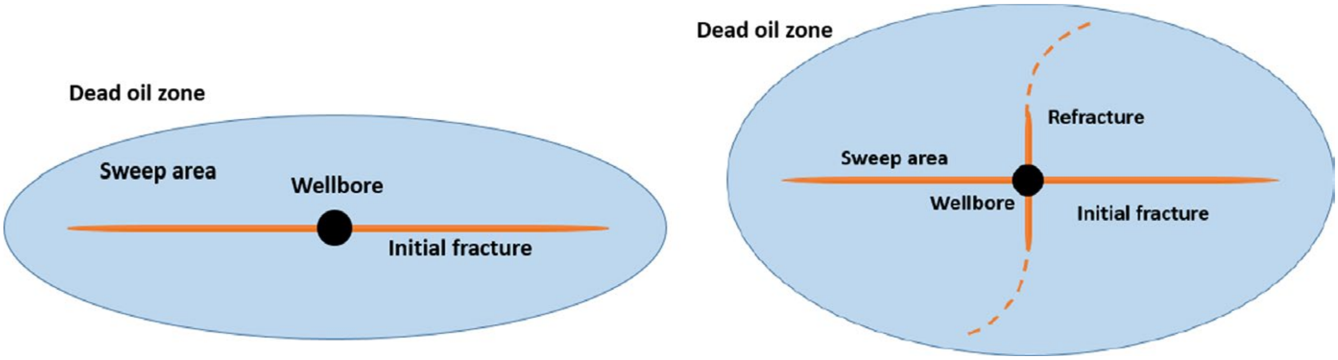


**FIGURE 1** Schematic diagram of refracturing using temporary plugging for diversion

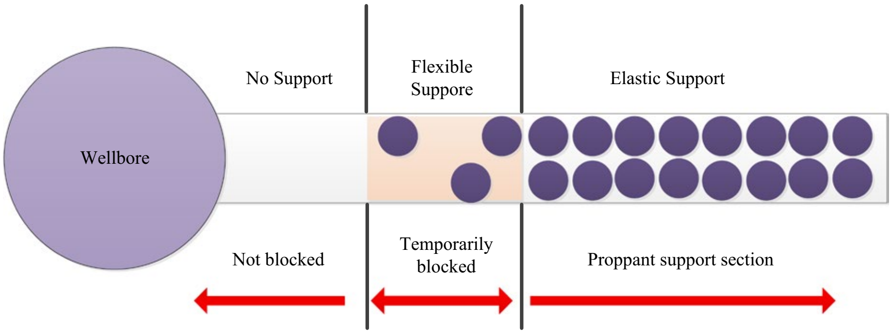


**FIGURE 2** Physical model of refracturing using temporary plugging for diversion

fractures or other high permeability areas to form filter cake bridge, subsequent fracturing fluid cannot enter the initial fractures and high permeability zones. The initial fractures can also lead to the redistribution of in-situ stress field in the near-wellbore region. Under the condition of in-situ stress difference, the azimuth of refracture initiation will be changed so that the reoriented refractures are created.

## 3 | EXPERIMENTAL ANALYSIS

### 3.1 | Experimental device and sample preparation

Experiments were carried out using a large-scale true triaxial fracturing simulation experimental system in National Engineering Laboratory for High Efficiency Drilling and Rock Breaking Technology at China's Northeast Petroleum University. The experimental system consists of a true triaxial test frame, fracturing pressure components, three-way pressure supply system, data acquisition and processing system, acoustic emission device, and operating station etc., the equipment shown in Figure 3.

Natural rock samples can reflect the properties of reservoir rocks better than cement samples, and the experimental results are more realistic. In this experiment, the natural outcrops of Jixi fault, which are similar to Daqing peripheral oilfield reservoir sandstone in terms of same structure and similar rock mechanics parameters, are used as experimental rock samples. The mechanical parameters of the two types of tight rock samples are shown in Table 1.

**FIGURE 3** Laboratory equipment picture

It can be seen from Table 1 that the average density of Daqing peripheral oilfield reservoir sandstone and Jixi fault outcrop sandstone rock samples is more than 2.48 g/cm$^3$, both of which are tight sandstones. The average values of elastic modulus, poison's ratio, uniaxial compressive strength, and tensile strength of two types of rock

**TABLE 1** Comparison of mechanical parameters of tight sandstone rock samples

| Rock samples | Number | Density (g/cm$^3$) | Elastic modulus (GPa) | Poisson's ratio | Uniaxial compressive strength (MPa) | Tensile strength (MPa) |
|---|---|---|---|---|---|---|
| Daqing peripheral oilfield reservoir sandstone | 1-1 | 2.53 | 9.30 | 0.23 | 62.78 | 7.10 |
| | 1-2 | 2.54 | 8.46 | 0.22 | 52.31 | 6.24 |
| Average | | 2.54 | 8.88 | 0.23 | 57.55 | 6.67 |
| Jixi fault outcrop sandstone | 2-1 | 2.48 | 6.82 | 0.25 | 58.63 | 6.27 |
| | 2-2 | 2.52 | 9.82 | 0.23 | 50.71 | 5.72 |
| Average | | 2.50 | 8.32 | 0.24 | 54.67 | 6.00 |
| Mean deviation | | 1.38% | 6.33% | 6.67% | 5.00% | 10.12% |

samples are very close, and the changes of those values are in the range of 10.12%. Therefore, it is appropriate to use the Jixi fault outcrop as rock samples to carry out the experiments of refracturing using temporary plugging for fluid diversion in Daqing peripheral oilfield's tight sandstone reservoir. Based on the previous field and the laboratory experiment,[22,23] we selected the degradable fiber temporary plugging agent during our experiment, one material which can form spatial network structure to seal crack channel. The temporary plugging agent was shown as Figure 4.

Using large-size cutting machine, angle grinders and other equipment, the large outcrop rocks were cut into cubes with dimensions of 300 mm × 300 mm × 300 mm for experimental rock samples, 10 rock samples were prepared for this study, and nine rock samples were used in the study as shown in Figure 5A. The temporary plugging agent is large molecular weight fiber-laden polymer. The experimental materials include water, dyeing agent, grinding sheet, seal ring, rubber rings and so on. The experiment was designed to simulate open hole completion, a hole was drilled in the center of one side. The depth of the hole is 14 cm, a pipe was cemented in the hole to represent wellbore.

**FIGURE 4** The temporary plugging agent

## 3.2 | Experimental parameters

Based on the geometric similarity criterion and fluid similarity criterion, the experimental parameters in this study are set and shown in Table 2. The experimental procedures are as follows: Firstly, using the experimental device, the rock sample was loaded with the stress according to Figure 5B, set the stress boundary conditions according to Table 2 and the initial hydraulic fracturing fluid was fresh water. Then stop the test when the rock samples started to break and the pressure relief occurred. Thirdly, the injection fluid was switched to a fracturing fluid containing the temporary plugging agent, the refracturing test was then started until the pressure increased and reached fracturing pressure. The pressure relief re-occurred, the rock sample fractured, and the refracture test completed.

This experiment is an exploratory experiment for the law of fracturing temporary plugging fracture propagation. Nine rock samples were tested, and five of the nine rock samples shown in Figure 5 were successfully tested which are listed boldly as # 2, # 3, # 6, # 8, # 9 in Table 2.

## 3.3 | Description of fracture morphology

The rock samples were opened along the fractures after the refracturing experiments. In the initial fracturing and secondary fracturing, different color dyes are added to the fracturing fluid used to trace the formed fractures. After the temporary blocking steering experiment, the data were obtained by measuring the lengths of different fractures and the angle between the two fractures. The measured fracture parameters are shown in Table 3. In order to describe the fractures more realistically, the three-dimensional visual images of the fractures were drawn and shown in Figure 6.

As shown in Figure 6, there is generally an angle between the initial fractures and refractures. The geometry of the two fractures is the shape of "T" or "L" because the temporary plugging agent has a soft plugging effect which can weaken the propagation of the initial fracture tip. Elbel showed that the direction of the maximum horizontal stress and the minimum horizontal stress changed because the


**FIGURE 5** The rock samples of Jixi Fault outcrop used in large-scale true triaxial fracturing lab test

**TABLE 2** Experimental parameters

| Rock samples | Vertical stress (MPa) | Maximum horizontal stress (MPa) | Minimal horizontal stress (MPa) | Horizontal stress difference (MPa) | Dyeing agent injection rate (mL/min) | Fiber concentration | Injection rate of fiber-laden polymer diversion fluid (mL/min) |
|---|---|---|---|---|---|---|---|
| # 1 | 16 | 15 | 14 | 1 | 1.2 | 1.00% | 5 |
| **# 2** | **16** | **15** | **13** | **2** | **1.2** | **1.00%** | **5** |
| # 3 | 16 | 12 | 8 | 4 | 1.2 | 1.00% | 5 |
| # 4 | 16 | 13 | 11 | 2 | 1.2 | 1.00% | 5 |
| # 5 | 16 | 12 | 10 | 2 | 1.2 | 1.00% | 5 |
| **# 6** | **16** | **15** | **11** | **4** | **5** | **1.00%** | **5** |
| # 7 | 12 | 10 | 8 | 2 | 5 | 1.00% | 5 |
| **# 8** | **12** | **8** | **4** | **4** | **6** | **1.00%** | **5** |
| **# 9** | **16** | **12** | **10** | **2** | **2.5** | **1.00%** | **5** |

**TABLE 3** Geometrical parameters of fractures

| Rock samples | Length of initial fracture (cm) | Length of refracture (cm) | Angle (°) |
|---|---|---|---|
| # 2 | 3.8 | 14 | 72 |
| # 3 | 12.2 | 8.7 | 33 |
| # 6 | 8.2 | 3 | 27 |
| # 8 | 10.5 | 4.7 | 33 |
| # 9 | 10.7 | — | — |

in-situ stress state of rock samples has been perturbed under the effect of temporary plugging agent. The refractures still propagate parallel to the maximum horizontal stress.[6]

## 4 | INFLUENCING FACTORS ANALYSIS OF FRACTURE MORPHOLOGY

### 4.1 | Injection rate of initial fracturing fluid

The injection rate of the initial fracturing fluid has a significant influence on the length and propagation of refractures. The initial fracture surface is always perpendicular to the minimum horizontal stress, which is not affected by the horizontal stress difference and the injection rate of the fracturing fluid. However, the effect of refractures propagation is the result of the initial fracturing fluid injection rate and the fracture closure pressure. The horizontal stress differences of rock samples #3, #6 and #8 were set the same in order to analyze the influence of initial fracturing fluid injection rate: when the initial injection rate of fracturing fluid is large (as for samples #6 and #8), the results of refractures propagation are poor; when the initial injection rate of fracturing fluid is small (as for samples #3), the propagation of refractures are long.

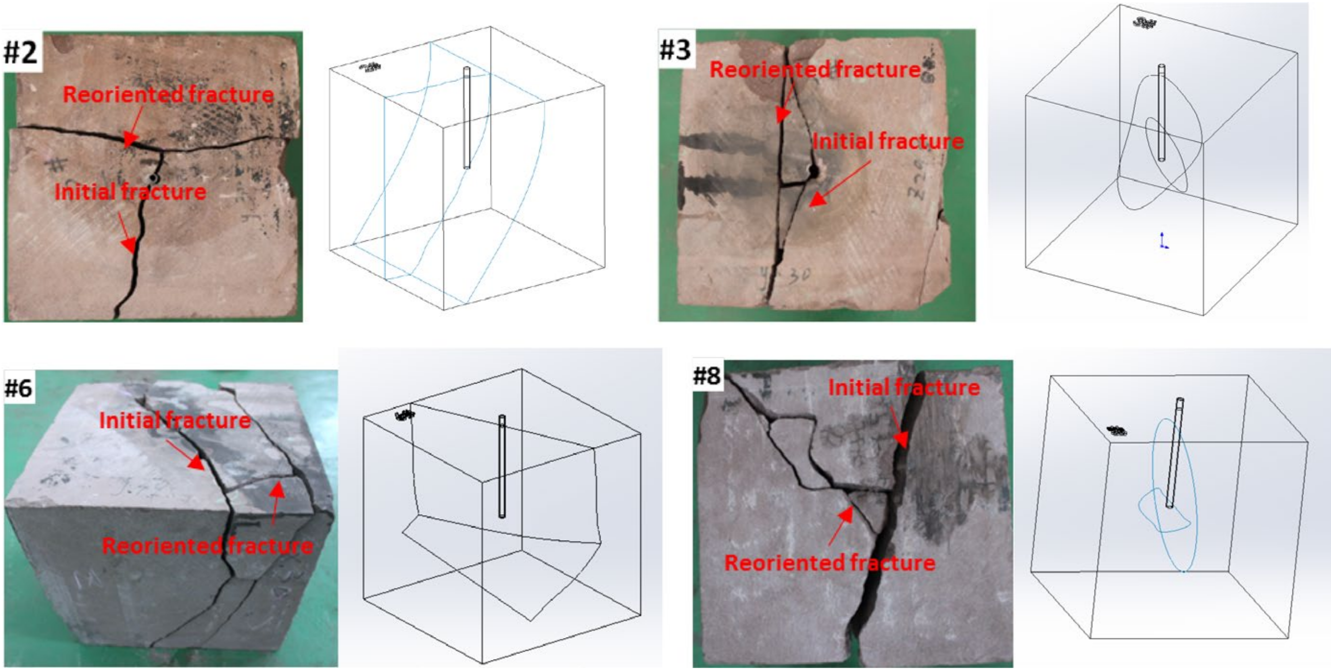


**FIGURE 6** The three-dimensional visual images of the rock samples and the fractures after the test

As the initial fracture and the refracture were marked by different color dye, the length of fracture was measured by the ruler and their angles are measured by a protractor. As shown in Figure 7, the initial fracture length of rock sample #3 is 12.2 cm, and the refracture is 8.7 cm. The initial fracture length of rock sample #8 is 10.5 cm and the initial fracture is classic oval fractures, the length of refracture is 1.7 cm, and the angle between the initial fracture and refracture is small which is shown in Figure 7. Based on the comparison of fracture morphology of rock samples #3, #6, and #8, we found that those rock samples with small injection rate of initial fracturing fluid have a longer refracture length. This is because the large injection rate of initial fracturing fluid resulted in larger initial fracture length, fiber-laden polymer fracturing fluid flowed out along the initial fracture, the temporary plugging effect was not ideal. It can be seen that the necessary condition for the success of the laboratory experiments of refracturing using temporary plugging is to adopt a low injection rate of fracturing fluid which is conducive to control the length of initial fractures.

The stresses used in tests on rock samples #3 and #9 are close, but the injection rates of initial fracturing fluid are different, the following is the comparison. As shown in Figure 7, the traditional oval-shaped bi-wing fractures formed in lab tests on samples #3 and #9. The initial fracture length of rock sample #9 was 10.7 cm and the fracture initiation location was the wellbore. The refracture was reoriented from the initial fracture using temporary plugging technology. It can be seen that the fracture initiation position and the length of the refractures are related to the injection rate of initial fracturing fluid. When the injection rate of initial fracturing fluid and size of the fractures are small, the blocking effect of the temporary plugging agent will be better, the refractures tend to form as reoriented fractures at the wellbore and the length of the refractures is longer.

## 4.2 | Horizontal stress difference

The available results show that, under the similar stress difference, the refracture initiation angles for sample #3, #6, #8 are similar (33°/27°/33°, respectively), regardless the different in the injection rate of initial fracturing fluid. Hence, we prefer that the injection rate of initial fracturing fluid has insignificant effect on the refracture initiation angle. We highlight that the horizontal stress difference is a critical factor of the fracture azimuth. The effect is analyzed by comparing the fracture morphology of rock samples under different horizontal stress differences. The horizontal stress difference of rock samples #6 and #8 was set to 4 MPa and the horizontal stress difference of rock sample #2 was 2 MPa. The reoriented refracture length of the rock samples #6 and #8 was 3 cm and 4.7 cm, respectively, while the reoriented refracture length of rock sample #2 was 14 cm. The angle between refracture and the initial fracture of the rock samples #6 and #8 was 27°, 33°, respectively, while it was 72° for rock sample #2. It can be seen that in the case of refracturing, when the horizontal stress difference is small such as the case for sample #2, the reoriented refractures are longer, the fracture angle is larger, and the large areas of previously untouched dead oil zone become the stimulated reservoir volume, those beneficial effect will be helpful for refractured wells to produce

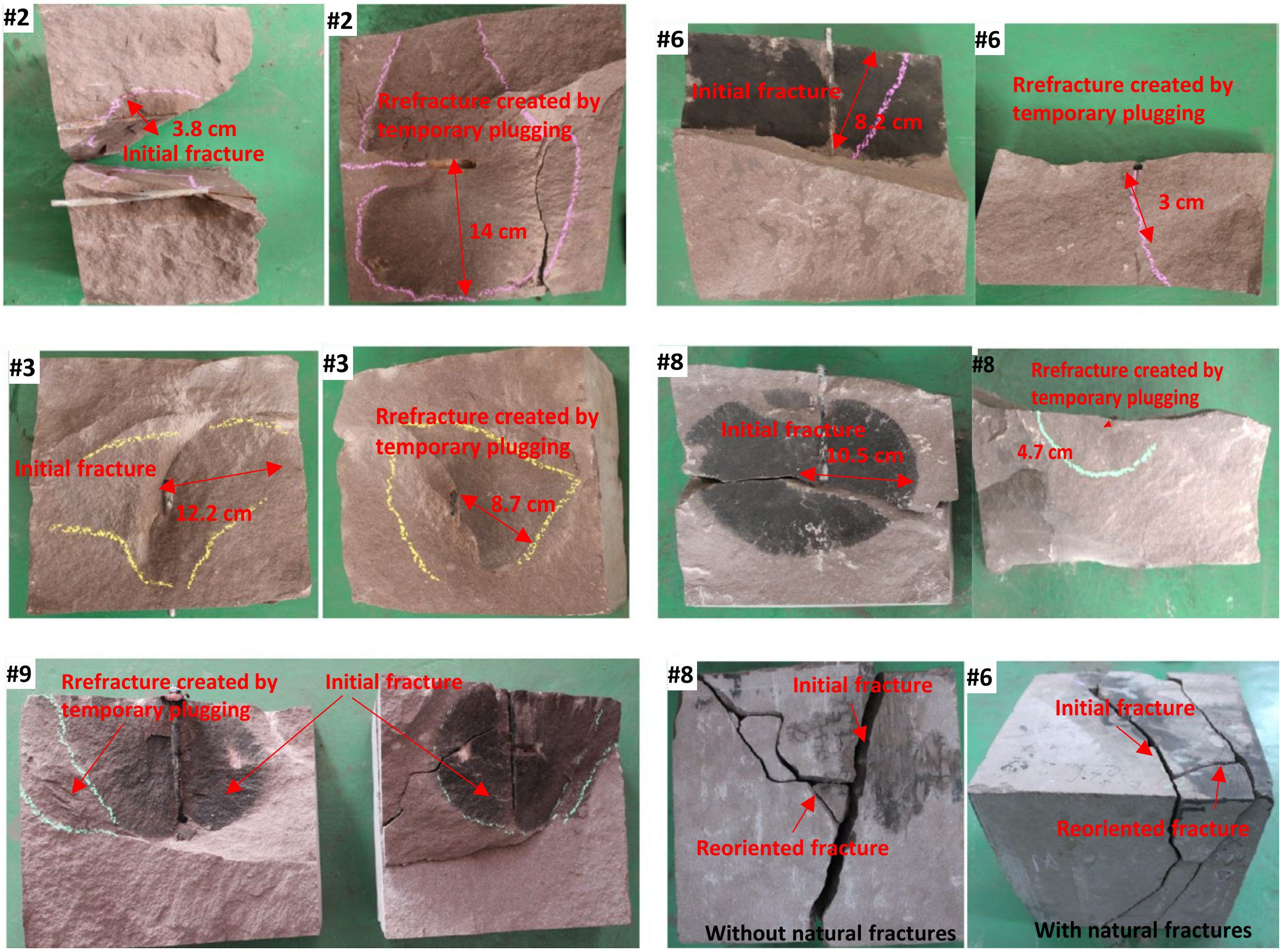


**FIGURE 7** Fracture morphology of different rock samples

the untapped reservoirs in initial fracturing treatment. The fracture morphology is shown in Figure 7. When the stress difference is large such as rock samples #6 and #8, the length of refractures is shorter, and the fracture angle is smaller. These findings of our study are consistent with the research results of Zhang and Siebrits.[8,10]

Research proved that the refractures will deviate from the direction of initial fractures when the injection pressure exceeds the maximum horizontal stress at the site or when the injection pressure is higher than the sum of the maximum horizontal stress and the tensile strength. As we know from the theoretical research that, in order for vertical fractures to extend distinctly and then ultimately form the supporting fissures, the following conditions have to be met[21]:

$$P_f = \frac{1}{2}(\sigma_h + \sigma_H) - \frac{1}{2}(\sigma_h - \sigma_H)\cos 2\theta + S_t, \quad (1)$$

where $\sigma_h$ is the minimum horizontal stress, $\sigma_H$ is the maximum horizontal stress, and $S_t$ is the rock tensile strength.

It is observed that under conditions of different stresses, the conditions of hydraulic fracture propagation are different, and the fracture extension stress is also different. When $\theta$ is 0°, $P_f \geq \sigma_h + S_t$ and when $\theta$ is 90°, $P_f \geq \sigma_H + S_t$.

When $\theta$ changes from 0° to 90°, the fracture extension stress changes in the following range:

$$\Delta P_f \geq \sigma_H - \sigma_h, \quad (2)$$

where $\Delta P_f$ is the fracture stress.

From the Equation (2), it can be seen that the fracture initiation and propagation is determined by the in-situ stress difference. The in-situ stress field is redistributed after the initial fractures are blocked, the smaller the in-situ stress difference is the easier the fracture propagation.

## 4.3 | Effect of natural fractures

The natural fractures have a significant influence on the refractures; micro fractures can effectively decrease the breaking pressure of the rock, influence the fracture initiation position, azimuth and propagation of refractures. Olson studied the stress interference between multiple hydraulic fractures and natural fractures, and reported that when refractures

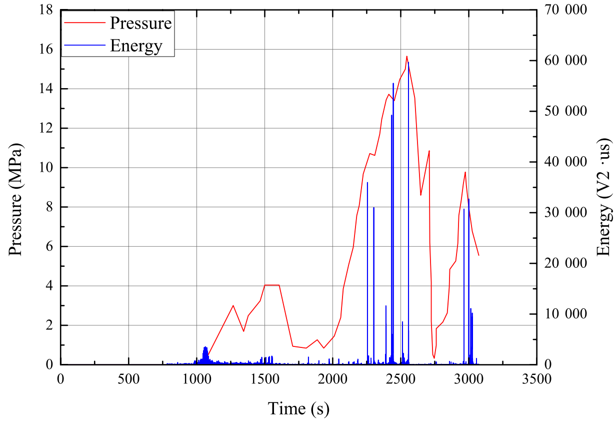


**FIGURE 8** Injection pressure, injection rate, acoustic emission signal profile of rock sample #6

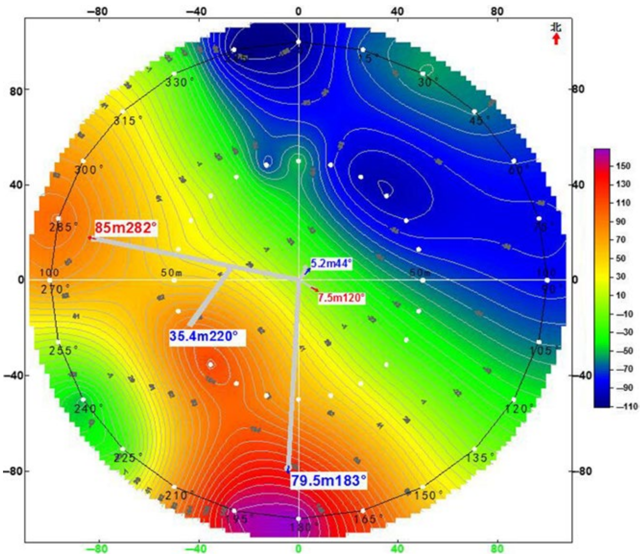


**FIGURE 9** Results of plane distribution of ground potential fractures

meet the natural fractures, stress propagation will change, causing the redistribution of in-situ stress.[24,25]

The hydraulic fracturing laboratory test was conducted on rock sample #6 with natural fractures and rock sample #8 without natural fractures. Two samples were in the condition of same horizontal stress difference. For rock sample #8, the fractures initiated and propagated perpendicular to the minimum horizontal stress and formed a classical elliptical symmetric bi-wing fracture. After the temporary plugging in rock sample #8, the refracture was reoriented to a certain angle with the initial fracture as shown in Figure 7. The fractures of rock sample #6 with the natural fractures also initiated and propagated perpendicular to the minimum horizontal stress; however, the fractures extended for 3 cm and stopped, and refractures were due to the redistribution of stress field caused by natural fractures.

According to the pressure curve of Figure 7, it can be seen that there are different degrees of pressure relief during the process of pressure increase, which is due to the fact that rock sample #6 had different natural fractures near the injection nozzle and fracturing fluid flow into the natural fractures causing pressure relief phenomenon. According to the acoustic emission signal, it can be seen that the acoustic emission signal reaches the maximum value when the rock is broken, and the acoustic emission signal is reduced and fluctuates when the signals encounter the natural fractures (Figure 8).

It can be seen that the existence of natural fractures has a great impact on the application of refracturing technology due to the stress field redistribution by natural fractures. When the fracture extends to the equivalent horizontal stress position, it will reorient and continue to propagate perpendicular to the minimum horizontal stress, refractures can increase the stimulated volume to further reach the dead oil zone and greatly improve the effect of refracturing technology using temporary plugging.

## 5 | FIELD VERIFICATION

The Xing'anling oil layer in Daqing peripheral oilfield has characteristics of thin thickness, poor physical properties and oil properties. The hydraulic fracturing treatment in Xing'anling reservoir can only create a limited sweep area and yield poor stimulation results. We take Well B in field test as an example, the maximum horizontal principal stress of Well B was 44.4 MPa, the minimum horizontal principal stress was 39.6 MPa, the horizontal stress difference was 4.8 MPa, Site experimental wells B to implement temporary plugging refracturing measures. After the initial hydraulic fracturing, the fiber-based mixed sand is injected into the well which is aiming to bridge the fracture in the near-well zone, forcing fracture reorientation.

The ground construction pressure increased from 28.2 to 34.6 MPa during the construction process and the construction net pressure increased from 1.5 to 6.1 MPa. According to the change of construction pressure, the formation layer formed several fractures. Two main fractures and one branch fracture were confirmed by postpress fracture morphology monitoring, as shown in Figure 9. The experimental results show that the temporary plugging refracturing can form the turning fractures effectively which increase the sweep area, and mine the remaining oil effectively. It is an effective method to mine the old wells again.

During the process of refracturing operation, the operating pressure on surface increased from 28.2 to 34.6 MPa and the operation net pressure increased from 1.5 to 6.1 MPa. According to the changes in operating pressure, multiple fractures were created by refracturing operation. Two main fractures and one branch fracture were confirmed by posthydraulic fracturing fracture morphology monitoring. The field test corroborated the laboratory testing: the temporary plugging in refracturing can effectively create reoriented fractures

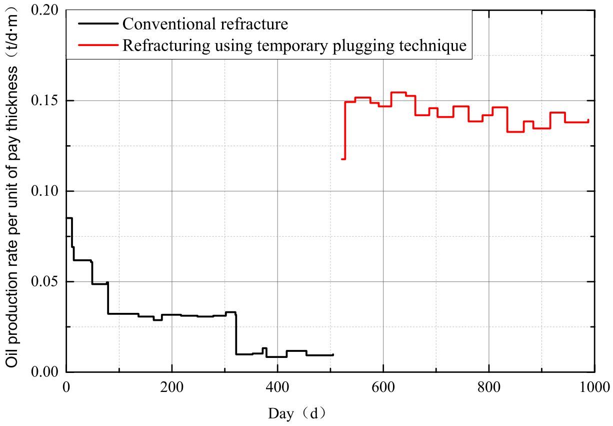


**FIGURE 10** Comparison of Well B with different hydraulic fracturing methods

which increase the stimulated volume and produce the untapped oil effectively. Refracturing with temporary plugging for fluid diversion is an effective treatment to improve the underperformed fractured wells.

The oil production per unit of pay thickness of Well B after initial hydraulic fracturing was 0.089t/d•m, and the cumulative oil production was 1058t during the stable production period of 300 days. After the implementation of refracturing with temporary plugging on Well B, the oil production per unit of pay thickness was 0.16 t/d·m, and the cumulative oil production was 3415t during the stable production period of 830 days. After the implementation of the refracturing, the oil production per unit of pay thickness and accumulated production rate exceeded those of the initial fracturing. Comparing to conventional refracturing technology, refracturing technology with temporary plugging can improve the oil production per unit of pay thickness by 2-3 times, the production performance was improved and increased significantly as shown in Figure 10. This is an effective way to further improve the performance of fractured wells.

## 6 | CONCLUSIONS

Through a series of large true triaxial stress refracturing with temporary plugging tests, this study confirmed that refracturing with temporary plugging technology is useful to form complex fractures in tight sandstone reservoirs and analyzed the geological and engineering factors that affect the fracture initiation and propagation. The main conclusions of this study are listed as follows:

1. Refracturing technology with temporary plugging can effectively create a new reoriented refractures, connect the dead oil zone, expand the stimulated volumes. Horizontal stress difference, injection rate of initial fracturing fluid and natural fractures are the main influencing factors of refracturing morphology.
2. The location of the fracture initiation is related to the initial fracturing fluid injection rate. When the initial fracturing fluid injection rate is small, the refracture tends to initiate at the wellbore, and the reoriented refracture is long. When initial fracturing fluid injection rate is large, the refracture tends to form at the initial fracture edge.
3. The horizontal stress difference has significant effect on the direction of fracture propagation. The smaller the horizontal stress difference, the more perpendicular for the propagation direction of the refractures and the initial fracture.
4. The presence of natural fractures affects the propagation of refractures. Refracturing with temporary plugging are often more prone to create complex fractures when the natural fractures are present in rocks.
5. The field application of this refracturing technology shows that the refracturing technique with temporary plugging can effectively create the new refractures and exploit the old dead oil zone, which is an effective method to improve the underperforming fractured wells.

## ACKNOWLEDGMENTS

The research was financially supported by National Natural Science Foundation of China, under contract No. 51490650, 51774093, and 51704074.

## ORCID

*Wei Li* http://orcid.org/0000-0003-4955-5341

## REFERENCES


1. Reese JL, Britt LK, Jones JR. Selecting economic refracturing candidates. 1994.
2. Liu H, Lan Z, Zhang G, et al. Evaluation of refracture reorientation in both laboratory and field scales. 2008.
3. Aghighi MA, Rahman SS. Initiation of a secondary hydraulic fracture and its interaction with the primary fracture. *Int J Rock Mech Min Sci*. 2010;47(5):714-722.
4. Malpani R, Sinha S, Charry L, et al. Improving hydrocarbon recovery of horizontal shale wells through refracturing. SPE/CSUR Unconventional Resources Conference. 2015.
5. Salz LB. Relationship between fracture propagation pressure and pore pressure. Soc. Pet. Eng. AIME, Pap.; (United States), 1977, spe-6870.
6. Elbel JL, Mack MG. Refracturing: observations and theories. SPE 25464, 1993.
7. Wright CA, Conant RA. Hydraulic fracture reorientation in primary and secondary recovery from low-permeability reservoirs. SPE annual technional conference & exhibition. Dallas, USA. 22-25 October, 1995.
8. Zhang GQ, Chen M. Dynamic fracture propagation in hydraulic re-fracturing. *J Petrol Sci Eng*. 2010;70(3–4):266-272.
9. Weng X, Siebrits E. Effect of production-induced stress field on refracture propagation and pressure response. *Chem Biol Drug Des*. 2007;71(5):494-500.

10. Siebrits E, Elbel JL, Detournay E, et al. Parameters affecting azimuth and length of a secondary fracture during a refracture treatment. Society of Petroleum Engineers, 1998:17–27.
11. Tan P, Jin Y, Han K, et al. Analysis of hydraulic fracture initiation and vertical propagation behavior in laminated shale formation. *Fuel*. 2017;206:482-493.
12. Guo T, Zhang S, Qu Z, et al. Experimental study of hydraulic fracturing for shale by stimulated reservoir volume. *Fuel*. 2014;128(14):373-380.
13. Song H, Gholami A, Bazunu G, et al. Investigation of fracture tip behaviour in visco-elastic/visco-plastic shale rocks and its effect on fracture propagation. SPE Asia Pacific Unconventional Resources Conference and Exhibition. 2015.
14. Taleghani AD, Gonzalez-Chavez M, Hao H, Asala H. Numerical simulation of hydraulic fracture propagation in naturally fractured formations using the cohesive zone model. *J Petrol Sci Eng*. 2018;165:42-57.
15. Li X, Lei X, Li Q, et al. Experimental investigation of Sinian shale rock under triaxial stress monitored by ultrasonic transmission and acoustic emission. *J Nat Gas Sci Eng*. 2017;43:110-123.
16. Mohammad MO, Aybar U. An economic evaluation on the re-fracturing treatment of the U.S. shale gas resources. SPE 171009, 2014.
17. Eshkalak M, Aybar U, Sepehrnoori K. An economic evaluation on the re-fracturing treatment of the U.S. shale gas resources. SPE Eastern Regional Meeting, 21-23 October, Charleston, WV, USA. 2014.
18. Siebrits E, Elbel JL, Hoover RS, et al. Refracture reorientation enhances gas production in barnett shale tight gas wells. SPE-63030-MS, 2000.
19. Xu C, Kang Y, Chen F, et al. Fracture plugging optimization for drill-in fluid loss control and formation damage prevention in fractured tight reservoir. *J Nat Gas Sci Eng*. 2016;35:1216-1227.
20. Diakhate M, Gazawi A, Barree RD, et al. Refracturing on horizontal wells in the eagle ford shale in south Texas – one operator's perspective. SPE Hydraulic Fracturing Technology Conference. 2015:248-257.
21. Song ZY, Wang XW, Ren YP, et al. The application of in-fissure divert fracturing technology in ultra-low. IPTC 13489,2009.
22. Wang XJ, Shang LT, Zhang MH, et al. Technical research and field test of degradable fiber fracturing. *Petrol Geol Oilfield Dev Daqing*. 2013;32(02):141-144.
23. Cohen CE, Tardy PMJ, Lesko TM, et al. Understanding diversion with a novel fiber-laden acid system for matrix acidizing of carbonate formations. 2010.
24. Olson JE. Multi-fracture propagation modeling: Applications to hydraulic fracturing in shales and tight gas sands. 2008.
25. Olson JE, Taleghani AD. Modeling simultaneous growth of multiple hydraulic fractures and their interaction with natural fractures. SPE Hydraulic Fracturing Technology Conference. The Woodlands, Texas, USA. 19-21 January, 2009.

**How to cite this article:** Li W, Zhao H, Pu H, et al. Study on the mechanisms of refracturing technology featuring temporary plug for fracturing fluid diversion in tight sandstone reservoirs. *Energy Sci Eng*. 2019;7:88–97. https://doi.org/10.1002/ese3.259