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The experimental study on hydraulic fracture propagation in dry hot rock

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ABSTRACT

As the increase of the demand towards energy as well as the requirement of green energy, we are doing pilot development project of HDR in Qinghai plateau. Up to now several hot dry rock(HDR) wells have been drilled and hydraulically fractured to increase heat exchange volume between injection and production wells. Among the wells, some interconnected well through the fracture system, but the others interconnection was poor. To understand fracture extension in HDR, a series experiments were done in the laboratory with poly-axial loading system. During the tests cubic granite samples were taken from outcrops in the plateau and gradually heated to targeted temperature before actual testing. In the tests, we investigated the effects of stress difference, pumping rate, fluid viscosity, rock texture and natural fractures on the hydraulic fracture propagation. It turns out that stress difference is the dominate element in fracture extension orientation and natural fractures and rock textures do affect fracture extension path when stress difference is minor. In addition, high pumping rate and fluid viscosity would result in the increase of fracture initiation pressure. Low temperature fracturing fluid injection such as fluid nitrogen on fracture complexity need further study.

1. INTRODUCTION

Geothermal resource development depends on the permeability and conductivity of the formations between the injector and the producer of hot dry rock reservoirs. So hydraulic fracturing is very important in the stimulation treatment of the reservoir. The characteristics of HDR formations and their geological reserve conditions are quite different from those of typical oil and gas reservoirs. Geothermal resources of hot dry rock exist in reservoirs of high temperature and low permeability. In addition, those reservoirs normally contain beddings, fractures and rock veins etc. Those discontinuities and textures would contribute to complex fractures that will enhance conductivity of fractures after reservoir stimulation treatment, but make fractures more complex and their propagation prediction much more difficult. Furthermore high reservoir temperature may result in different rock deformation behavior than those of normal oil and gas reservoirs. Fracture propagation during reservoir stimulation have been widely studied physically or numerically, but not so much in EGS research[1-8] yet. To understand fracture initiation and propagation in hydraulic fracturing we did fracturing simulation in the laboratory with outcrops collected in Qinghai plateau, where HDR pilot projects have been implanted. The outcrops were cut and grinded to cubic samples of 300*300*300mm with a hole drilled from the top surface of the sample, then cased for pressure loading to initiate fractures. In the tests, different fluid viscosity, pumping rate, stress difference etc. were used to investigate their effects on fractures initiation and propagation. It demonstrated that stress difference and natural fractures are the dominate elements in fracture initiation and complexity and high temperature has minor influence on them but initiation pressure.

2. SAMPLE PREPARATION AND HEATING SYSTEM

Large outcrops were taken form Qinghai plateau which are the same stratigraphic system with the targeted HDR reserves, refer to figure 1. Those outcrops were cut and grinded as shown in figure 2. A small diameter hole was drill from the top surface to a certain depth. Then a metal tube was insert the hole and sealed with O-ring and left a little section at the bottom of the hole uncased as openhole.

Figure 1: Outcrops for sampling

Figure 2: Prepared samples for laboratory hydraulic fracturing tests

It consists of heater, heat insulation board, thermal transducer and temperature controller. Heaters were put on the surfaces of the sample except for the bottom as shown in figure 3. Heat insulation board were put between the sample and loading plates to ensure constant temperature maintained within the sample. Temperature controller were installed on the surface on the sample and within the small diameter tube for real time temperature measurement and control. After set up, the system was then loaded in the poly-axial testing system under servo control.

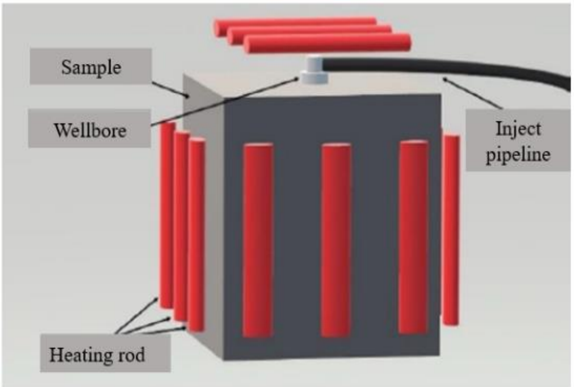


Figure 3: Heaters installation arrangement

3. INFLUTIAL ELEMENTS IN FRACTURE PROPAGATION

In reservoir stimulation, some treatment parameters in addition to geological conditions will determine fractures propagation and final geometry. In the experimental study, we took testing temperature, pumping rate, fluid viscosity, stress difference and extreme low temperature as potential elements. Some samples were scanned with CT and the propagation path were carefully observed from the dyed frac fluid after the experiments.

3.1 Fracture propagation under different temperature

To investigate temperature effects on fracture propagation, the tests were run at 120℃ and 200℃, respectively. It was found in the CT scan before the test that there was a horizontal natural fracture close to the bottom side of the sample, but it did not communicate with the hole. The temperature was raised to 120℃ step by step and hours of waiting time was set for thermal equilibrium between every heating step.

During fracturing under the temperature of 120℃, fracture initiated from openhole section and extended along the maximum horizontal stress direction forming double wing fractures. When the fracture reached the natural fracture beneath the openhole section, fracture communicated with the natural fracture and continue to extend to the surface of the sample, see figure 4.

In the test under the temperature of 200℃, no obvious textures or natural fractures were found in the sample. Double wing fractures initiated from the openhole section and a certain degree of extension deviation from the maximum stress direction was observed due to minor stress difference, refer to figure 5.

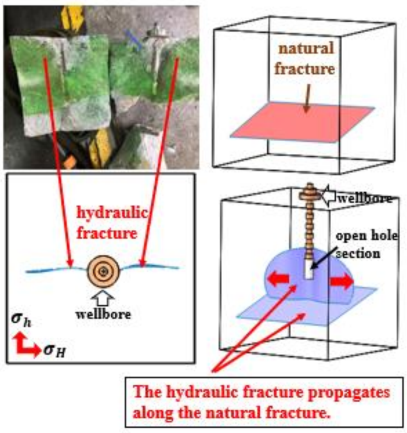


Figure 4: Fractures propagation under 120℃

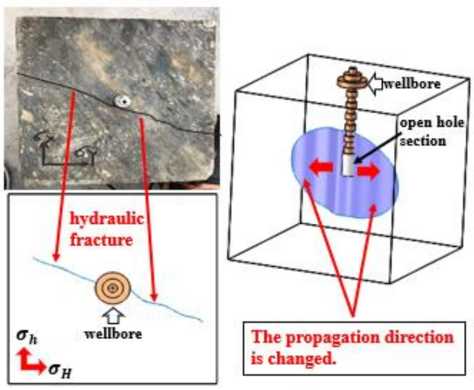


Figure 5: fracture propagation under 200℃

It demonstrated that fracture propagation was mainly controlled by natural fractures or discontinuities rather than temperature, but it might raise fracturing pressure due to rock mechanical behavior change under high temperature.

3.2 Fracture propagation under different pumping rate

Tests were run at 200℃ and with the same load configuration and frac fluid viscosity, and the pumping rates were 30ml/min and 1ml/min, respectively. After the tests, core plugs were drilled across the fractures. It was found in CT scan that fractures broke the grain of the sample and continue to grow under high pumping rate, but they would turn around the grains under low pumping rate, refer to figure 6. It indicated that fracture complexity is easier to achieve with low pumping rate.

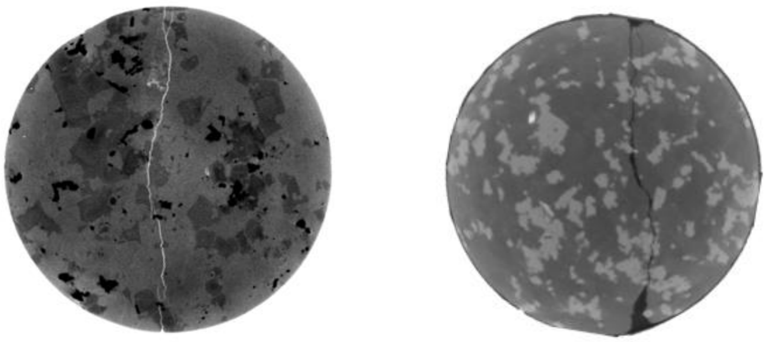
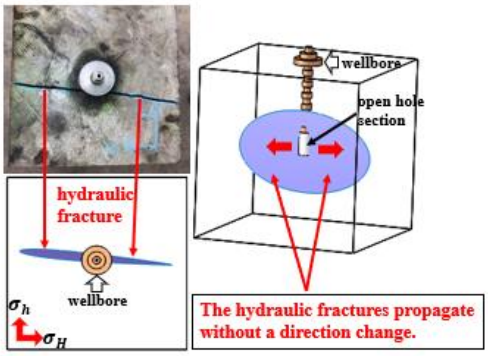


Figure 6: Fracture propagation among and cross grains of HDR sample

3.3 Fracture propagation with different frac fluid viscosity

Tests were run at 200℃, stress difference 6MPa and pumping rate 5ml/min with fluid viscosity 1 mPa·s and 33.1 mPa·s, respectively. It showed that double wing fractures initiated from the openhole section and extended along the maximum stress direction to the surface of the sample for both cases, see figure 7 and 8. However, some fracture tortures were observed in the fractured sample with lower frac fluid viscosity.



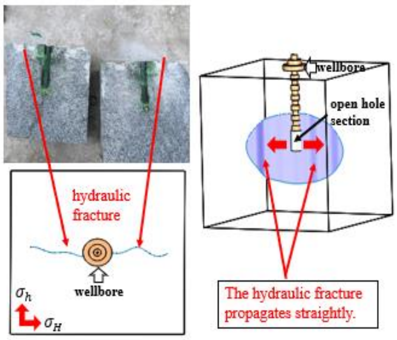


Figure 7: Fracture propagation with high viscosity fluid **Figure 8: Fracture propagation with low viscosity fluid**

3.4 Fracture propagation under different stress difference

In the tests pumping rate and frac fluid were kept unchanged at 200℃, the effect of stress difference in fracture propagation were investigated. It showed that double wing fractures initiated at openhole section along maximum stress direction for both cases under stress difference 3MPa and 6 MPa, respectively. However, some degree of fracture propagation deviation from maximum stress direction happened under lower stress difference, but not for the higher stress difference case.

Similar to the tests under room temperatures, stress difference are also the dominate element in fracture propagation orientation and fracture complexity.

3.5 Fracture propagation with extreme low temperature fluid

Besides those tests of fracture initiation and propagation under high temperature, tests with extreme low temperature frac fluid were also done with liquid nitrogen. It was found that irregular fractures were created around the borehole and it might be caused by sharp stress change resulting from huge thermal gradient, see figure 9.

Figure 9: Samples after the test with extreme low temperature fluid

4. CONCLUSIONS

It was found through series of experiments that hydraulic fracture propagation in HDR is similar to those formations of oil and gas reservoirs. It is related to geological conditions and stimulation treatment parameters. In most cases, double wing fractures will be created and extended along maximum horizontal stress. Natural fractures or discontinuities and rock textures may torture or even change the path of fracture propagation, and so does horizontal stress difference. High pumping rate and frac fluid viscosity would create less tortured and complex fractures, and they are not beneficial to heat exchange in thermal development.

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