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Impact of the distance between pre-existing fracture and wellbore on hydraulic fracture propagation

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ABSTRACT

To understand the impact of the distance between pre-existing fracture(s) and wellbore on hydraulic fracture propagation, hydraulic fracturing experiments are conducted using a triaxial hydraulic fracturing testing system in this work. Rock-like specimens with either one pre-existing fracture or two pre-existing fractures are used and divided into two groups. Specimens in Group 1 have just one pre-existing fracture, while specimens in Group 2 have two pre-existing fractures. The influence of the distance between pre-existing fracture(s) and wellbore on hydraulic fracturing is studied. The results demonstrate that the distance between pre-existing fracture(s) and wellbore can influence fracture propagation behavior. Under the same confining stress condition when the pre-existing fracture is close to the wellbore ($L_1/D \le 2.0$ in this work, L_1 is the distance from the pre-existing fracture to wellbore, D is the wellbore diameter), the hydraulic fracture may propagate towards the pre-existing fracture tips. When the pre-existing fracture is located far from the wellbore ($L_1/D \ge 7.0$ for Group 1 specimens, $L_1/D \ge 5.0$ for Group 2 specimens), the impact of the pre-existing fracture tips on hydraulic fracture propagation diminishes. The hydraulic fracture may propagate towards the middle of the pre-existing fracture. After passing or crossing the pre-existing fracture, the hydraulic fracture turns to the maximum horizontal stress direction gradually.

1. Introduction

Hydraulic fracturing as a stimulation technology has been widely used in the oil and gas industry to increase flow and production from low permeability reservoirs to the wellbore. It is very important to predict the propagation direction of hydraulic fracture. Because of the complex geological conditions including the stress state and natural fractures in reservoirs, the initiation and propagation of hydraulic fractures are often complicated. Scaled experimental study in laboratory is an effective way to understand the mechanisms of hydraulic fracture initiation and propagation. Many researchers have studied relevant problems associated with hydraulic fracturing from several aspects.

The experimental research of Hubbert and Willis (1957) has shown that hydraulically induced fractures should be formed approximately perpendicular to the least principal stress. Some of the experimental works have concentrated on the formation mechanism of hydraulic fractures (Abass et al., 1996; de Pater et al., 1994; Fan and Zhang, 2014; Hou et al., 2017; Wen et al., 2016). Some have focused on hydraulic fracture geometry (Jia et al., 2013; Liang et al., 2017). Many researchers have experimentally analyzed the propagation path of hydraulic fractures (Bohloli and de Pater, 2006; Chitrala et al., 2013; Guo et al., 2014; Hakim and Karma, 2005; Ma et al., 2017; Zeng and Wei, 2017 Zhou et al., 2016). These studies have analyzed the effects of multiple factors, including horizontal stress anisotropy, fracturing fluid viscosity, and flow rate on the initiation and propagation direction of hydraulic fracture.

Extensive experimental studies focused on the interaction between hydraulic fractures and natural fractures have been performed. Some have explored different interactions (termination, penetration, deflection, and attraction) between hydraulic fractures and natural fractures under different experimental conditions. The stress difference and the approaching angle (Blanton, 1982; Gu et al., 2012; Lamont and Jessen, 1963; Liu et al., 2014; Yan et al., 2011) are important factors to

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Nomenclature

L_1	the distance from the pre-existing fracture to the wellbore
L_2	the distance from the pre-existing fracture tip to the wellbore
D	the wellbore diameter
$G(\theta)$	energy release rate
$G_c(\theta)$	fracture toughness
θ	fracture propagation direction

influence hydraulic fracture propagation behavior when the hydraulic fracture reaches to the pre-existing fracture. These studies show that high horizontal stress difference and large approaching angle are favorable factors for hydraulic fracture to cross the pre-existing fracture. The influence of the pre-existing fracture styles has also been studied considering one pre-existing fracture (Warpinski and Teufel, 1984; Yan et al., 2011) or pre-existing fracture networks (Yao et al., 2008). Their studies indicate that pre-existing fractures near the wellbore play a great role in hydraulic fracture initiation. Large-scale pre-cracked specimens (1000 × 1000 × 1000 mm) have been studied in the laboratory to investigate the interaction between hydraulic fractures and natural fractures (Mao et al., 2017). Their results show that the pre-manufactured crack is able to supply an initiation point for crack propagation. The anisotropic tensile strength of layered formations (Ma et al., 2017a, 2017b) has received attention in the analysis of fracture pressure. Their studies show that for layered formations the larger the anisotropy, the lower the fracture pressure.

Numerical simulation methods are also efficient ways to provide results on the interaction between a propagating hydraulic fracture and existing fractures (Akulich and Zvyagin, 2008; Nagel et al., 2013; Zou et al., 2017). Among numerical simulation methods, the extended finite element method (XFEM) is an effective tool to simulate the hydraulic fracturing process (Gordeliy and Peirce, 2013; Khoei et al., 2015; Lecampion, 2009).

It has been known that the fracture propagation direction may be driven either by stress or by the pre-existing fracture (Jaeger et al., 2009; Gao et al., 2017). Although previous studies have revealed that the stress difference and the approaching angle impose great influences on hydraulic fracture propagation, the impact of the distance between the pre-existing fractures and wellbore on hydraulic fracture propagation has not been studied. This research is mainly focused on this topic using rock-like specimens containing either one pre-existing fracture or two fractures.

We will introduce specimen preparation and testing equipment in Section 2. The experimental results on hydraulic fracture propagation are then analyzed and discussed in Sections 3 and 4, followed by some conclusions made in Section 5.

2. Testing equipment and specimen preparation

The experiment apparatus used in this study consists of two parts: a confining stress control device and a hydraulic pressure loading device (Fig. 1). The schematics of these specimens are shown in Fig. 2. The dimensions of the specimens are listed in Table 1. L_1 is the distance from the pre-existing fracture to the wellbore, L_2 is the distance from the pre-existing fracture tip to the wellbore, and D is the wellbore diameter. The rock-like testing specimen is a mixture of cement, sand, and water with a mass ratio of 1:3.5:0.65. The cement type is #325 Portland cement and the sand grain size is smaller than 1.25 mm. The mixture is mixed well and poured into a mold (0.15 m × 0.15 m × 0.15 m) containing the pre-existing fracture(s). The pre-existing fractures are simulated by inserting one or two pieces of rectangular drawing paper (0.09 m in height, 0.03 m in width and 0.0005 m in thickness).

The procedures for specimen preparation are as follows. First, sand is poured into a sieve with 1.25 mm mesh to remove particles bigger than 1.25 mm. Second, cement, sand and water are weighted and mixed in a blender for 5 min. Third, paper slices to simulate natural fractures are placed into the mold. Last, cement, sand, and water mixture are poured into the mold. The mold with the fresh cement mixture is then vibrated at room temperature for 3 min. The specimens are taken out of the mold 24 h afterwards, for curing in the curing box at a constant temperature of 20 °C and humidity over 95% for 28 days. After curing, each specimen block is drilled with a cylindrical cavity (0.08 m in length and 0.01 m in diameter) to simulate the wellbore and a steel tube (0.065 m in length, 0.01 m in diameter and 0.001 m in thickness) is fixed to the wellbore by structural adhesive to simulate the well pipe. Underneath the pipe there is a 0.015 m orifice used to simulate the open hole section to initiate hydraulic fracture. The Young's Modulus and tensile strength of the rock-like material for making the specimens are 302 MPa and 0.875 MPa, respectively.

To study the influence of the location of the pre-existing fracture on hydraulic fracture propagation, rock-like specimens are divided into two groups for testing. Specimens containing one pre-existing fracture are in Group 1 and specimens containing two pre-existing fractures are in Group 2. The pre-existing fractures strike directions are all parallel to the diagonal of the block and the dip directions parallel to the wellbore in the vertical direction, as shown in Fig. 2. In this work, the confining stress is kept constant and the length of the pre-existing fractures is kept constant as well. The directions of confining stresses are shown in

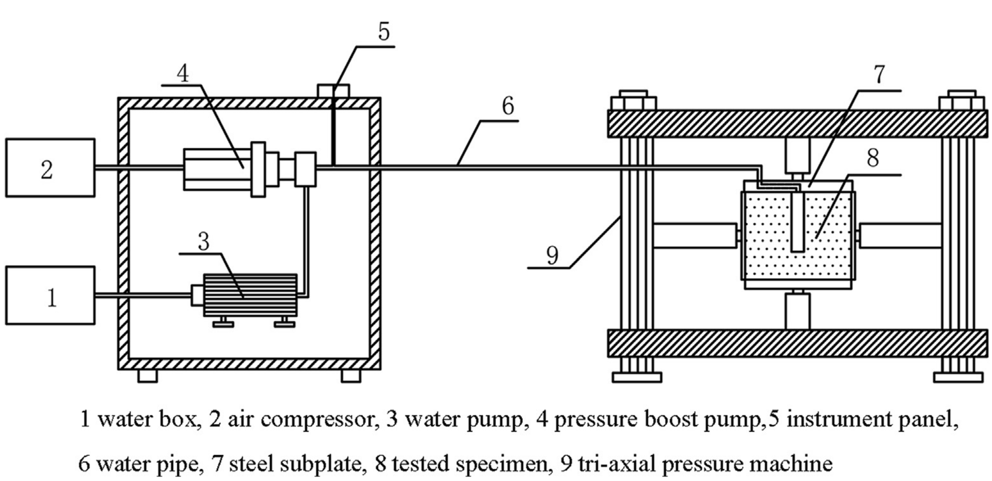

Fig. 1. Hydraulic fracturing experiment apparatus.