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RESEARCH PAPER

Hydraulic fracture propagation geometry and acoustic emission interpretation: A case study of Silurian Longmaxi Formation shale in Sichuan Basin, SW China

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Abstract: A series of laboratory fracturing experiments was performed on samples mined from an outcrop of the Silurian Longmaxi Formation shale in the Sichuan Basin, using a true triaxial fracturing simulation system. To reveal the characteristics of acoustic emission (AE) response in hydraulic fracture (HF) propagation, the HF propagation geometry obtained by specimen splitting and CT scanning technology was compared with the interpretation results of AE monitoring. And the difference of hypocenter mechanism between hydraulically connected and unconnected regions was further discussed. Experimental results show that the AE events distribution indicates well the internal fractures geometry of the rock samples. Numerous AE events occur and concentrate around the wellbore where the HF initiated. Sparse AE events were presented nearby bedding planes (BPs) activated by the HF. AE events tended to be denser where HF geometry was more complex. The hydraulically connected region was obviously distinct with the spatial distribution of AE events, which resulted in the overestimation of stimulated reservoir volume (SRV) based on micro-seismic mapping result. Both tensile and shear events occurred in the zone connected by the HFs, while only shear events were observed around BPs which were not hydraulically connected. Thus, the hydraulically connected and unconnected region can be identified in accordance with the hypocenter mechanism, which is beneficial to improve the accuracy of SRV evaluation.

Key words: shale; bedding plane; hydraulic fracture; propagation geometry; acoustic emission; CT scanning

Introduction

Shale formations are characterized by low porosity and permeability, high brittleness and heterogeneity, and rich bedding planes (BPs) and natural fractures (NFs). As shale reservoirs have no natural productivity in general, large-scale volume fracturing treatment is necessary to create stimulated reservoir volume (SRV) for commercial development[1–3]. Microseismic monitoring is one of the effective means to evaluate fracture morphology and estimate the SRV[4–7]. Researchers have conducted a large number of studies on the law of hydraulic fracture (HF) propagation in shale reservoirs. They mainly revealed the spatial distribution of hydraulic fractures in rock samples through rock dissection and CT scanning[8–11]. To acquire more information on fracture propagation, acoustic emission (AE) monitoring has been applied to laboratory fracturing simulation experiments, and gradually become an effective means for monitoring the behavior of fracture propagation. The principle of AE monitoring is similar to that of microseismic monitoring[12–13]. Stanchits et al.[14] investigated the influence of the viscosity of fracturing fluid on fracture initiation pressure of permeable sandstone by AE monitoring. Then, they studied the behavior of fracture propagation in isotropic sandstone with artificial interfaces and in heterogeneous shale with natural BPs using AE monitoring[15]. Liu et al.[16] studied the propagation of fracture height in sandstone reservoirs under different interlaminar stress differences by AE monitoring. Hou et al.[17] and Heng et al.[18] conducted shale fracturing simulation experiments and preliminarily analyzed the generation mechanism of fracture network with AE monitoring. However, all these works focused on HF propagation laws, but didn't cover the corresponding relationship between the hydraulically connected region and explanation result of SRV. It is necessary to find out whether all the AE events represent the creation of

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hydraulic fractures. Therefore, in this study, laboratory fracturing experiment was conducted on shale samples taken from Silurian Longmaxi Formation, Sichuan Basin using a true tri-axial fracturing simulation system. The results of sample dissection and CT scanning were compared with those of AE positioning to reveal the response characteristics of AE during fracture propagation, and the differences between hydraulically connected and unconnected region in AE event types were analyzed from hypocenter mechanism.

1. Experimental method

1.1. Sample preparation

The natural shale samples used were collected from shale outcrop of the Longmaxi Formation, Sichuan Basin. Mineral composition analysis suggests that the shale composition is dominated by silica and clay minerals, with quartz content of 50.6%, clay content of 33.4%, carbonate content of 9.8%, and pyrite content of 6.2%. Table 1 shows the mechanical parameters from lab test.

A large block of shale was cut into 30 cm × 30 cm × 30 cm cube along directions parallel to BP and perpendicular to BP. For simulating the horizontal well fracturing, one central hole of 1.6 cm in diameter and 16.5 cm in depth was drilled on a surface perpendicular to the BP direction. A wellbore (steel pipe) with the external diameter of 1.5 cm, internal diameter of 0.8 cm and length of 13.5 cm was placed in this hole. High-strength epoxy resin adhesive was used to cement the wellbore in the center blind hole, leaving a 3.0 cm open-hole section at the bottom. During the experiment, the fluid was injected into the wellbore from the liquid injection pipe, generating high pressure at the well bottom, so HF would initiate from the open-hole section. The CT scanning image before fracturing experiment shows that the shale sample has rich beddings with abvious aperture in local parts (Fig. 1).

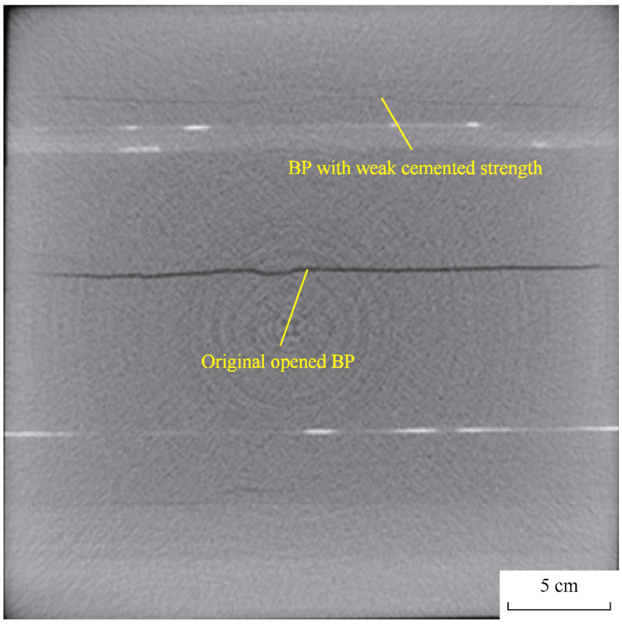

Fig. 1. CT scanning image of the rock sample in the direction perpendicular to the wellbore before fracturing.

1.2. Experimental apparatus and procedure

The experiment was carried out using a true tri-axial fracturing simulation system[19]. To simulate the real formation stress condition, tri-axial stresses were loaded separately in three directions through the hydraulic stands. The maximum loading stresses were 15 MPa along the X axis, and 30 MPa in the Y and Z axes. A sixteen-channel acoustic emission monitoring system was introduced to localize HF spatial distribution and interpret the hypocenter mechanism. To improve the accuracy of localization results, three or four acoustic emission sensors were arranged on five loading platens of the rock sample, except that with the wellhead. A coupling agent was also used to improve the contact between the sensors and rock surfaces.

Table 1. Mechanical parameters of shale samples.

Coring direction	Young's Modulus/ GPa	Poisson's ratio	Compressive strength/ MPa	Tensile strength/ MPa
Parallel to BP	36.36	0.241	284.1	2.37
Perpendicular to BP	37.18	0.236	300.9	6.71

The specific experimental procedure was as follows:

(1) To connect the liquid injection line and place the shale sample on the tray of the simulation system with the BP along horizontal direction and the wellbore along the X axis.

(2) To install the loading platens with AE sensors on five surfaces of the shale sample and connect the data acquisition line with the AE data acquisition system.

(3) To push the hydraulic piston inside the chamber, apply vertical stress σ_v along the Z axis, and apply maximum horizontal principle stress σ_H along the Y axis and minimum principle horizontal stress σ_h along X axis and maintain stable.

(4) To start the fluid injection system, and pump the low-viscosity slick water with tracing agent into the wellbore at constant rate, meanwhile, record the variation of wellhead pressure and AE signals during the fracturing experiment.

(5) To take rock sample out after the experiment, observe the fracture geometry inside the sample by CT scanning and sample dissecting, and distinguish the hydraulically induced fractures and original open BPs based on the coloring of the fracture surface.

(6) To interpret AE monitoring data, obtain the spatial distribution of AE events and then compare with the actual hydraulically connected region.

1.3. Experimental parameters

The complex fracture in the shale reservoir is a three-dimensional fracture network formed by HF activating natural fracture system on the horizontal plane and multiple BPs in the vertical direction. Therefore, the mechanism of HF propagation is related to both horizontal stress difference ($\Delta\sigma_h$ =