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Research Article

Application of surface–downhole combined microseismic monitoring technology in the Fuling shale gas field and its enlightenment☆

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Abstract

The Fuling shale gas field in the Sichuan Basin, as a national shale gas demonstration area, is the largest commercially developed shale gas field in the world except those in North America. The fracturing technology in the mode of "well factory" has been applied widely in the gas field, but it is necessary to perform further investigation on the way to evaluate effectively the fracturing effect of multi-well platform "well factory" and the distribution laws of its induced fracture networks. In this paper, the fractures induced by the "well factory" at the JY 48 platform were real-time monitored by a surface–downhole combined microseismic monitoring technology. The geometric size and extension direction of artificial fractures induced in the model of "well factory" fracturing in the Jiaoshiba block of Fuling Shale Gas Field were preliminarily understood. Moreover, the fracturing parameters under the mode of "well factory" were recognized by using the comprehensive interpretation results of surface–downhole combined microseismic monitoring technology, together with the SRV fracturing prediction chart. Eventually, the distribution laws of artificial fractures during the "well-factory-zipper" fracturing in the Fuling Shale Gas Field were clarified definitely. This paper provides guidance for the optimization of fracturing parameters at the later stage.

Keywords: Sichuan Basin; Fuling shale gas field; Well factory; Fracturing (rock); Surface microseismic; Downhole microseismic; SRV prediction; Artificial fracture

Volumetric fracturing, or volumetric stimulation, aims at producing a spatial network of hydraulic fractures by brittle-rock shearing and slipping actions so as to increase stimulated reservoir volume (SRV), initial production and ultimate recovery [1,2]. Hydraulically induced microseismic events could be acquired, processed and interpreted to monitor the effects of hydraulic fracturing and to avail the adjustment and optimization of fracturing and development plans.

By 2015, surface and borehole microseismic surveys of 20-well-time had been implemented in the Fuling shale gas field to gain an insight into parameter optimization and effects of single-well fracturing. But there is little knowledge about artificial fracture distribution law on well-factory zipper fracturing; here fracture height, width and direction may be estimated by jointly using surface and borehole microseismic data [3].

1. Objectives

Microseismic events may be acquired at the land surface or in a borehole [4]. In a surface survey, a lot of geophones are placed at the surface, far from the intervals to be fractured, to collect signals from the 3D subsurface space. In a borehole survey, some borehole geophones are laid in the wells, generally close to the intervals to be fractured, to record signals from the 2D space. The former has high lateral positioning accuracy and the latter has high vertical positioning accuracy.

It is the first time in the Fuling shale gas field, the Sichuan Basin to conduct surface and borehole microseismic

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monitoring for 3 horizontal wells at the JY 48 platform. The objectives include characterizing the occurrence and generating the process of hydraulic fractures and evaluating reservoir stimulation so as to optimize fracturing operation [5].

2. Data acquisition

A horizontal well group composed of 3 wells (JY 48-1HF, JY 48-2HF and JY 48-3HF) was deployed at the JY 48 platform for shale gas production from the Upper Ordovician Wufeng Fm and the lower part of the Lower Silurian Longmaxi Fm. Staged sand fracturing with pumped bridge plugs was conducted in January, 2015. For a further estimation of shale gas deliverability and hydraulic fracture distribution, joint surface and borehole microseismic monitoring was also performed along with hydraulic fracturing. In the borehole survey, geophones were placed in a vertical well, JY 41-X, between Well JY 48-2HF and JY 48-3HF. The geometry of the surface survey is shown in Fig. 1 (the area to be monitored is circled by a green line and red lines represent survey lines). The borehole and surface geometries are plotted together in Fig. 2.

In the process of hydraulic fracturing, 56 perforated and fractured intervals (including 2 for calibration) with 131 clusters were monitored. As per preliminary evaluation, field data have good signal-to-noise ratio and thus could be used for microseismic interpretation [6].

3. Data interpretation

3.1. Source interference analysis

As per field data examination, signals were contaminated locally on some survey lines. Near offsets are much noisy. Middle offsets have strong signals and high signal-to-noise ratio. Far offsets exhibit weak noises and signals [7]. In view of survey line distribution shown in Fig. 1, surface noises

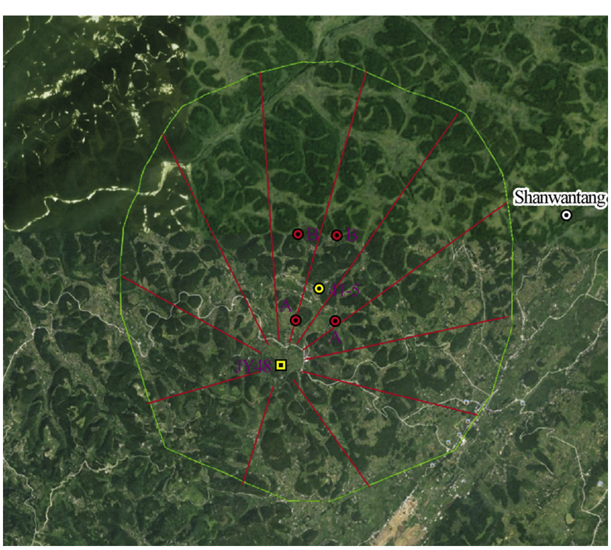

Fig. 1. Geometry of the surface survey.

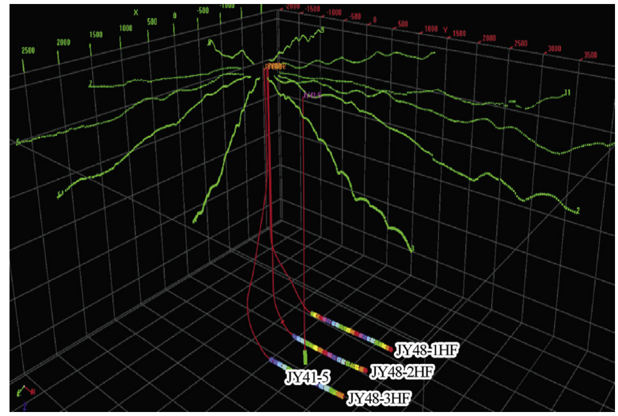

Fig. 2. Geometries of the borehole and surface surveys at the Well Group JY 48.

were mainly caused by nearby vehicles and human activities in neighbouring densely-populated regions and near-offset noises originated in the operation of fracturing equipment. Due to spherical spreading and absorptive attenuation, far offsets exhibit weak signals.

Raw signals corresponding to strong, medium and weak microseismic events were separated for single-line noise analysis. The results show that microseismic events, detonating cord signals and perforating signals were contaminated by similar noises. Except those events with strong energy, medium and weak events are much noisy; thus the overall signal-to-noise ratio is low. These noises should be eliminated for high-precision imaging [8].

3.2. Data processing

The processing workflow includes (1) data format conversion from SEG-D into an internal format in FracListener and antialiasing filtering, (2) noise attenuation, (3) bandpass filtering, (4) AGC to equalize trace-to-trace amplitude, (5) geophone static correction based on perforation tests, (6) weak microseismic signal extraction and P-wave first arrival picking, and (7) microseismic event positioning [9]. The greatest challenge was weak signal extraction.

3.3. Data interpretation

3.3.1. Surface microseismic interpretation

In order to address the issues of weak signal energy resulting from the shielding effect caused by limestone outcrops and strong surface noises, microseismic events were detected by automatic identification and manual QC and then positioned by source scanning after noise reduction and perforating location correction. The positioning results were examined to eliminate those imaging points with large errors [10]. After in-site processing, the statics were optimized in light of some strong microseismic events, detonating cord signals and perforating signals for travel-time based positioning. Weak signals were enhanced. Extracted head arrival time was inverted after relative positioning; this process was