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Research Article

Real-time microseismic monitoring technology for hydraulic fracturing in shale gas reservoirs: A case study from the Southern Sichuan Basin☆

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Abstract

Zipper hydraulic fracturing in multiple wells with long horizontal sections is a primary solution means to increase the shale gas production rate and efficiency and to reduce the cost in Southern Sichuan Basin. Microseismic based fracturing monitoring can be used for real-time imaging of hydraulic fractures, so it has been widely used to evaluate the fracturing effect of shale gas reservoirs and to direct the optimization and adjustment of fracturing parameters. In China, however, the microseismic fracturing monitoring on fracturing of shale gas reservoirs cannot be used to evaluate the fracturing results until the fracturing operation in the pad wells is completed according to the parameters which are designed prior to the fracturing monitoring. Its evaluation results can merely provide a guidance for the fracturing parameters of the next pad wells instead of the wells in operation. As a result, the real-time effect of microseismic fracturing monitoring is out of work. In view of this, the fractures induced by zipper hydraulic fracturing in multiple shale gas wells with long horizontal sections in the southern Sichuan Basin, was real-time imaged by using the combined technology of radially arranged microseismic surface monitoring and microseismic well monitoring on the basis of real-time positioning method. The fracturing results were assessed and used in real time for the optimization of prepad fluid parameter, perforation and temporary plugging additive releasing time, so as to effectively avoid repeated fracturing and uneven fracturing effects and improve fracturing stimulation effects. This method is applied in two well groups. It is shown that the average shale gas production rate is increased by 2–5 times. Furthermore, microseismic fracturing real-time monitoring plays a vital role in real-time evaluation of fracturing effect and real-time optimization of fracturing parameters, so it can be used as the reference and should be popularized further.

Keywords: Shale gas; Microseismic; Real-time monitoring; Horizontal well; Zipper fracturing; Well monitoring; Surface monitoring; Production increase; Southern Sichuan Basin

The Lower Silurian Longmaxi Formation in southern Sichuan Basin is rich in shale gas resources [1–3], but shale gas exploration and production is subject to complex topographic conditions (with elevation difference of 400 m), inconvenient transportation, dense population and inefficient technologies. For the promotion of shale gas exploration and production, zipper fracturing in several wells with long horizontal sections was introduced from North America [4–6]. The longest horizontal section in this prospect reached 2000 m. In view of little knowledge about fracturing parameters and results because this technique is still in its infancy in China, it is necessary to conduct microseismic monitoring in real-time evaluation and parameter optimization. But microseismic data were usually used for post-fracturing assessment after the operation was fulfilled with pre-fracturing design parameters [7–9]; the results of assessment may only be used for the operation in the next platform well. Few wells were monitored in real time by hydraulically induced microseism.

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On the other hand, microseismic monitoring meets challenges in multi-well zipper fracturing. Microseismic events may be acquired at the land surface or in a borehole [10−12]. A borehole microseismic survey has high signal-to-noise ratio. But due to the limitations of recording geometry and azimuth, there are no observation wells with appropriate spacing for monitoring 3−4 wells in zipper fracturing. Thus a well not included in synchronous fracturing is used as the observation well (equipped with geophones) and consequently cannot be monitored by borehole survey. In a borehole survey, vertical positioning is more accurate than lateral positioning. A surface microseismic survey is not constrained by azimuth or observation wells but tends to be affected by topographic conditions, especially in a mountainous region with a vertical detection distance of 3500 m. Thus a surface observation suffers from intense signal attenuation, weak energy recorded and intractable velocity modeling. In a surface survey, lateral positioning is more accurate than vertical positioning [13−16]. In this paper, we use a radially-oriented surface survey combined with borehole survey to image hydraulic fractures and optimize fracturing parameters in real time.

1. Microseismic data acquisition and processing

1.1. Data acquisition

In the radially-oriented surface microseismic survey, 8−20 survey lines with 1000−3000 groups of geophones were laid around the wellhead at the center; group interval is 20 m. The borehole survey was equipped with 40-level 3-component geophones placed close to the sections to be fractured; geophone spacing is 15 m (Fig. 1).

1.2. Data processing

GeoMonitor, a self-developed system for microseismic monitoring, was used for real-time positioning. (1) Build an interval velocity model. The initial velocity model was built with sonic log derived velocity and seismic interpreted horizons and then corrected by joint surface−borehole positioning of perforation signals. The velocity model was finally accepted when the error of perforation positioning was less than the predefined value. (2) Conduct preprocessing. This included static correction and noise reduction for surface data and noise reduction, vector rotation, and automatic microseism picking for borehole data [17−19]. (3) Conduct real-time positioning [20]. A joint positioning method through automatic searching across 3D grids was employed to position microseismic events in real time. The delay time of real-time positioning was less than 10 s (4) Display microseismic events in 3D space. The positioned microseismic events in the 3D space were delivered to a fracturing engineer for fracturing evaluation and parameter optimization [21].

2. Real-time evaluation and parameter optimization

After real-time positioning, microseismic events projected in the 3D space may be observed by top view or side view to examine hydraulic fractures. The density of events represents the intensity of rock failure and the intensity increases with density. The extension of events denotes the extension of fractures; the lengths in parallel with and perpendicular to the direction of extension are equal to the length and width of the fractured zone, respectively. The height of events in vertical direction is equal to the height of the fractured zone. The volume swept by microseismic events indicates stimulated reservoir volume. Thus fracturing evaluation and parameter optimization in real time could be realized through microseismic events analysis.

2.1. Pad fluids

Hydraulic fracturing, especially fracture length [22,23], relies greatly on the selection of pad fluid.

Initially 20 m^3 acidizing fluid was injected in Well A (the 4th section) was injected with acidizing fluid of 20 m^3, directly followed by linear gel. Microseismic events, as shown in Fig. 2-a, manifest inefficient fracturing operation. Hence the pad fluid parameters for the 5th section were adjusted: 20 m^3 acidizing fluid followed by 100 m^3 slick water, then by linear

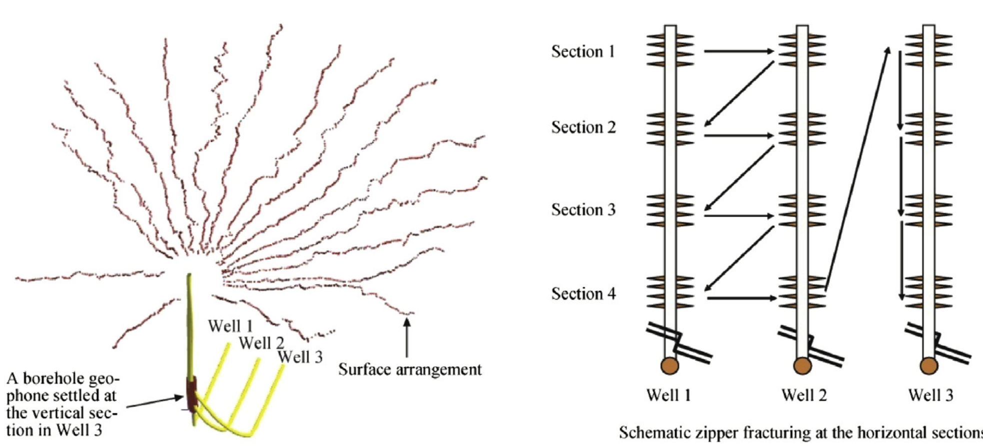

Fig. 1. Schematic surface and borehole microseismic survey layouts.