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Monitoring and evaluating the volume fracturing effect of horizontal well

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ABSTRACT

The volume fracturing technology has been the key technology to develop extra-low permeability, ultra-low permeability, and even the tight oil and gas reservoirs. Based on the real case of a volume fracturing horizontal well in Jilin Oilfield, the microseismic (MS) technology was used to monitor the effect of volume fracturing, and the MS monitoring results were analyzed. Using the data of fracturing operation and MS monitoring, a single-well numerical simulation model with stimulated reservoir volume (SRV) was built, to evaluate the volume fracturing effect of horizontal wells. The results of the study show that the MS monitoring technology can predict the fracture distribution, size, and direction of the volume fracturing horizontal well. The volume fracturing technology of horizontal well can enhance the initial oil yield of single wells and cumulative oil production. Both of the volume fracturing and CO_2 miscible flooding technologies are effective methods to develop tight oil reservoirs.

1. Introduction

The conventional hydraulic fracturing techniques cannot satisfy the development of unconventional oil and gas reservoirs (Wang et al., 2012, 2014a); therefore, volume fracturing techniques have emerged in recent years. Using volume fracturing measures, the stimulated reservoir volume (SRV) can be realized to achieve industrial production in tight reservoir (Wu et al., 2011, 2012). The volume fracturing techniques mainly include the vertical well multi-layer fracturing technique and horizontal well staged fracturing technique (Wang et al., 2013a, 2014b). These techniques are usually used to stimulate unconventional reservoirs such as shale gas and tight oil reservoirs abroad (Wang et al., 2014c, 2013b). The applied range of volume fracturing techniques is expanded to extra-low and ultra-low permeability reservoirs in China. Many oilfields such as Changqing oilfield, Jilin oilfield have conducted volume fracturing measures and achieved good results (Shi et al., 2014; Li et al., 2013; Wei et al., 2013). Using volume fracturing techniques, the effect of volume fracturing measures must be evaluated (Wang et al., 2014d). Currently, the main methods to monitor and evaluate the volume fracturing effect are microseismic (MS) monitoring, well test interpretation, production dynamic analysis, and reservoir numerical simulation (Shi et al., 2014; Cipolla et al., 2010; Mirzaei and Cipolla, 2012).

Studies on the evaluating of volume fracturing effect are still relatively few in China. We used a volume fracturing horizontal well #Y in Jilin Oilfield as an example and used MS monitoring and single-well numerical simulation techniques to evaluate the effect of this volume fracturing horizontal well. The horizontal well #Y is located in the Yi-45 block, and its aim development reservoir is the Shuang-2 formation, whose top surface structure form is a narrow and long syncline from north east to south west. The well is located at the center of the syncline zone. The formation dip is approximately $7^\circ - 9^\circ$, and the fracture is not developed. The reservoir porosity is 12%, and the permeability is $0.3 \times 10^{-3}\ \mu m^2$.

2. Volume fracturing and MS monitoring

2.1. Volume fracturing of horizontal well

Volume fracturing techniques commonly follow the treatment standards: slickwater, low concentration proppants, high displacement, and a large amount of fluid; these techniques aim to open and communicate about natural fractures. The horizontal well #Y was constructed using multi-stage hydraulic sand fracturing in April 2013. The number of fracturing stages is 14, the fracturing

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thickness is 49.2–83.4 m, the rock breakdown pressure is 30–55 MPa, and the average sand ratio is 26.7%. The amounts of fracturing pad fluid and sand-carrying fluid are 3209 m^3 and 2573 m^3, respectively. Three different sizes of proppant were used in the fracturing process. The total amounts of proppant, after-pad fluid, base fluid, and crosslinking agent are 683 m^3, 845 m^3, 7037 m^3, and 63.5 m^3, respectively.

2.2. MS monitoring

MS refers to the vibration phenomenon caused by wave propagation in the rock when the rock mass fractures. MS monitoring is usually achieved by placing a seismometer in the wellbore of a vertical or horizontal well and receiving the signals of compressional waves and shear waves to calculate the location of the MS events (Xu et al., 2013). The schematic of MS monitoring is shown in Fig. 1.

By placing a seismometer in the adjacent vertical well #Y45-2, MS monitoring was conducted in the volume fracturing process of horizontal well #Y. The MS monitoring results are shown in Fig. 2. Fourteen colors of dots (in the web version) represent MS singles in fourteen different fracturing stages. After the MS mapping of horizontal well #Y were analyzed, the following results were obtained.

(1) According to the MS mapping of horizontal well #Y, we know that the fracture network is between 50 and 95 m high, whereas the fracturing target reservoir is only 5.5 m thick, so the entire target reservoir was completely fractured in the vertical direction. However, the vertical fracturing scale is so large that other formation such as the water formation may be fractured, which is undesirable. We suggest that the fracturing parameters should be adjusted to reduce the fracturing height when other fracturing measures are conducted on this formation in the future.
(2) Fig. 2 shows that some stages such as the sixth and seventh stages were not well fractured. Their reservoir properties are poor, and the reservoir contains large shale content, so the wellhead pressure was significantly higher than those in other well fractured stages. Fig. 2 shows that the fracture network of the sixth and seventh stages extended approximately 200 m. If the fracturing pressure continues increasing, these two stages can become reconstructed to some extent. However, considering that the reservoir properties of these two stages are poor, the oil content is notably small with little contribution to the entire well production, and increasing the fracturing pressure may induce high risk. Therefore, only 0.5 m^3 of sand was added when the fracturing treatment was stopped in time.

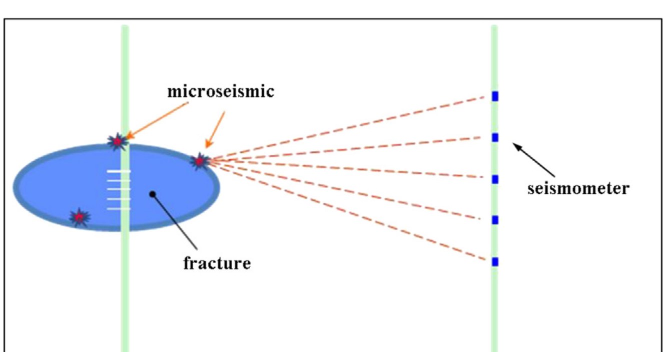

Fig. 1. Schematic of the MS monitoring.

(3) The fracture networks are asymmetric and distribute near the EW direction on both sides of the well trajectory. The east wing grew better than the west wing, which indicates that the east side has a thicker and better sand body than the west side. This MS mapping result is consistent with the previous sand thickness distribution map. Therefore, MS monitoring can be used to more finely portray the reservoir distribution.

3. Evaluating the volume fracturing effect

After the analysis of the MS monitoring results, the volume fracturing effects, including the fracture distribution, size, and the direction of volume fracturing horizontal well, were understood preliminarily. To further study the effect of volume fracturing on the production capacity, the numerical simulation model of volume fracturing horizontal well should be built.

3.1. PVT and MMP experiments

The PVT experiments were conducted, in which the oil sample from the aim reservoir, and the PR3 equation of state (EOS) was applied in PVT regression to match the experimental data of single flash vaporization test, differential liberation, and constant composition expansion experiments. 8 pseudo-components of the crude oil were grouped and their mole fractions are shown in Table 1.

In order to study the development effect of the CO_2 miscible flooding in the volume fracturing well group, the slim tube experiment of the crude oil sample is conducted. The result of the experiment shows that the minimum miscible pressure (MMP) of the crude oil and CO_2 is 20.1 MPa, which is shown in Fig. 3.

3.2. Evaluation model

Based on the reservoir and fluid parameters of Shuang-2 formation in the Yi-45 block, the reservoir compositional numerical simulation model of horizontal well #Y with SRV was built (Fig. 4). The horizontal wellbore length is 650 m. The SRV range of the model was provided from the MS mapping and modified with the history matching of production data. There are four vertical wells located in the boundary of the well group. Other basic parameters of the numerical simulation model are shown in Table 2.

3.3. Volume fracturing effect analysis

The dark blue zone (in the web version) in Fig. 4 represents the SRV region of horizontal well that was stimulated by volume fracturing, the blue zone (in the web version) represents the unstimulated region, and the light blue zone (in the web version) represents the SRV region of vertical well. By interpreting the MS monitoring data results, we know that the 5.5 m thickness reservoir was completely fractured in the longitudinal direction. According to the well test interpretation results, the permeability of the unstimulated region was set to 0.3 mD. The permeability of the SRV region was significantly improved because the fracture network can be formed by volume fracturing. The fracture network was realized by local grid refinement (LGR) technology in the numerical simulation model. The permeability of fracture network was adjusted to 30 mD by history matching.

The pressure buildup well test was performed in the horizontal well #Y during October 1–7, 2013. Fig. 5 shows the pressure plane distribution maps of the pressure drop (October 1, 2013) and pressure buildup (October 7, 2013). The pressure drop mainly occurred in the SRV region, and the shape of the pressure drop is consistent with the shape of the SRV. The pressure near the