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Comparative study on the analysis methods of fracture pressure interference in shale oil three-dimensional fracturing

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Introduction

With the improvement of oil exploration and development technology, the proportion of tight reservoirs in new reserves is getting higher and higher. As an important part of tight reservoirs, thin interbedded tight reservoirs account for more and more. According to investigation and evaluation, about 30% of the oil and gas in the world are stored in thin interbeds of sand and mudstone. Therefore, the rational development of such reservoirs is an important means to actively adjust the energy structure of our country and realize energy replacement. Thin interbedded low-permeability reservoirs of countries generally demonstrate the following geological characteristics: deeply buried with sandstone layer and mudstone layer appearing alternately, sand bodies scattered and developed, multiple vertical layers with small single-layer thickness, poor reservoir physical properties with low reserves abundance, small pores, narrow throats, and low permeability (Surdam et al., 1982; Surdam and Crossey, 1985; Seewald, 2003; Sonnenberg et al., 2009). The development of thin interbedded low-permeability reservoirs is facing many challenges, such as low oil production rate, low recovery, low single-well production capacity, and great difficulty in production stabilization (Du et al., 2014; Feng et al., 2020; Sheng et al., 2020). Meanwhile, the fracture morphology is hard to control, and the stage number in a horizontal staged fracturing can be very limited. The results are far from satisfying (Zhang et al., 2014; Li et al., 2016; Tan et al., 2017; Sheng et al., 2019; Zhou et al., 2020). Without a sufficient understanding of interlayer fracture pressure interference in a fracturing operation, the effective development of thin interbedded low-permeability reservoirs would be restricted (Liu et al., 2018; Lu et al., 2020; Meng et al., 2020). Therefore, it is of crucial importance to accurately analyze and identify the interlayer fracture pressure interference and quantitatively describe the actual fracturing effect and fracture morphology of thin interbedded shale oil reservoirs. At present, microseismic technology, tracer technology, and pressure monitoring technology can all be used to analyze the pressure channeling of interlayer fractures in fracturing construction. However, the results obtained by single application of one of the three methods are not accurate. By analyzing the advantages and limitations of the three methods, a comprehensive application of the three methods can better describe the actual fracturing operation effect and fracture morphology.

Geologic features

The No. 58 platform studied in this paper is a typical thin interbedded shale oil reservoir. The "Sweet Spot" can be divided into seven sub-layers from top to bottom, and the oil layers are mainly distributed in the first, second, and third sub-layers. The average effective porosity of the oil layer is 8.36%, and the average permeability is 0.0047mD. The platform has a total of eight wells in the well area, and the three-dimensional development deployment mode is adopted. The well spacing is 200 m, and each well has undergone fracturing operations. The average fracturing process has 40 stages, the average cluster spacing is 5.8 m, and the average interval is 46 m. In this paper, pressure interference analysis was carried out on thin interbedded shale oil fracturing fractures in platform No. 58.

Longitudinal interference analysis and identification with different fracture monitoring methods

Microseismic technology

Microseismic monitoring technology can inversely locate the focal position through the study of the focal mechanism in the process of monitoring the fracture propagation behavior of reservoir fracturing, and determine the formation process, fracture orientation, length, and other information of fractures (Chunyan et al., 2018; Salishchev et al., 2020). Well 5 and Well 3 were selected for research. The vertical microseismic monitoring data of Well 5 shows that the upper fracture height is 20 m and the lower fracture height is 24 m. The vertical microseismic monitoring data of Well 3 shows that the upper fracture height is 18 m and the lower fracture height is 24 m. Well 5 and Well 3 are in the second sub-layer with an average layer thickness of 10.4 m. The thickness of the upper adjacent layer, the first sub-layer, is 5.9 m, and the thickness of the lower adjacent layer, the third sub-layer, is 8.6 m. By comparing the vertical thickness of the second layer and its adjacent layers, it is easy to conclude that the fracture pressures of Well 5 and Well 3 have vertically interfered with the first, second, and third sub-layers (Wu et al., 2017; Vadim et al., 2018; Xiong et al., 2019; Zhang et al., 2019).

Tracer technology

The tracer enters the formation synchronously with the fracturing fluid during the fracturing process. During backflow after fracturing, the backflow fluid is intensively sampled at a certain time interval to obtain the tracer backflow curve. The purpose of fracturing effect evaluation can be achieved by interpreting the tracer backflow curve (Ruixiang et al., 2007; Lingtao et al., 2022). Tracers were injected into Well 3 located in the second sub-layer, and then they were detected in Well 2 located in the first sub-layer and Well 4 located in the third sub-layer. This indicates that the fractures have connected the first, second, and third sub-layers. Well 5 and Well 6 are close to Well 4 and vertically located in the same layer; tracers were also detected in them. Meanwhile, the fracture morphology in the fracturing stage is characterized by analyzing the tracer breakthrough curve (BTC) of fracturing fluid recovery (Li et al., 2016). When tracers were injected into Well 4, the tracer production in Well 3 would decrease with time, indicating that the vertical fractures that connect the third and the second sub-layers might close. According to the identification results of fracture pressure interference based on tracer monitoring data (Lisa et al., 2019; Abdulaziz et al., 2020; Fu et al., 2020; Zhao et al., 2020), we could conclude that the fracture pressures of Well 3 have vertically interfered with the first, second, and third sub-layers.

Pressure monitoring technology

In the process of fracturing construction, the initiation and extension of hydraulic fractures in three-dimensional space are related to construction pressure. The decline speed of the bottom hole (wellhead) pressure after the pump is stopped can reflect the filtration property of the formation. Therefore, the purpose of fracturing effect evaluation can be achieved by analyzing the change in fracturing pressure. Well 3 was selected as the monitoring well to study the dynamic pressure changes of adjacent wells during the fracturing operation. The results showed that the pressures of Wells 1, 2, 4, 5, and 6 were significantly increased. The noticeable pressure increases of Well 1 in the upper, first sub-layer indicated that the pressure of Well 3 had interfered with the upper oil layer. The pressure of Wells 4, 5, and 6 located in the third sub-layer also increased significantly, indicating that the pressure of Well 3 had interfered with the lower, third sub-layer. In summary, the identification results of fracture pressure interference based on pressure interference monitoring data (Shahbazi et al., 2015; Escobar et al., 2021; Seth et al., 2021) suggested that the fracture pressures of Well 3 have vertically interfered with the first, second, and third sub-layers.

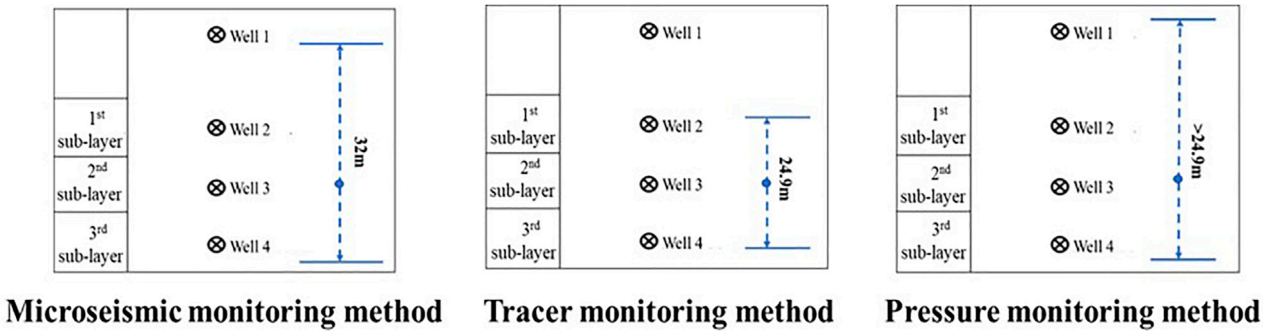

FIGURE 1
Comparative analysis of different identification methods.

Comparative analysis of different identification methods

Taking Wells 1, 2, 3, and 4 as examples, the analysis results of the three analysis methods of fracture pressure interference are shown in Figure 1.

The comparison results showed that the tracer monitoring method was the most accurate to analyze and identify fracture pressure interference. When tracers were injected into a certain well and could be detected in other wells, it was clear that these wells were connected and there were inter-well interferences. The microseismic monitoring method could locate the approximate locations of fractures with pressure interferences, but the predicted ranges were generally wider than the actual ones. The pressure monitoring technology could roughly generate the spread ranges of fracture pressure interference based on the dynamic pressure changes of adjacent wells, but the generated ranges were generally broader than the ones given by the tracer monitoring method. Though the tracer monitoring method showed the highest accuracy, its detection results can be sensitive to the locations of tracer injection and detection wells; for example, for layers without detection wells, the inter-well connectivity can be hard to identify. Therefore, to generate a more comprehensive fracture pressure interference report, the three methods should always be used together. Take the tracer monitoring method as the main body, use the microseismic monitoring method generated specific fracture ranges as constraints, and conduct further analysis by referring to the monitored pressure data in actual fracturing operations. Synthetical applications of the three methods are beneficial to the effective analysis and identification of interlayer fracture pressure interference. Furthermore, the fracture morphology in thin interbedded shale oil fracturing and the actual fracturing effect can be more accurately characterized and evaluated.

Conclusion

(1) The tracer monitoring method was the most accurate to analyze and identify fracture pressure interference. The scope of the microseismic monitoring method and pressure monitoring technology is wider than that given by the tracer monitoring method.
(2) Synthetic applications of the three methods are beneficial to the effective analysis and identification of interlayer fracture pressure interference. In addition, the fracture morphology in thin interbedded shale oil fracturing and the actual fracturing effect can be more accurately characterized and evaluated.

Author contributions

YC: investigation and research,conceptualization, writing—Original draft preparation, data curation XZ: resources, translation LH: modify analysis GS: supervision, typesetting.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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