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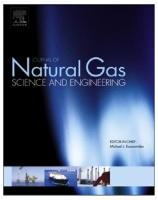

The qualitative and quantitative fracture evaluation methodology in shale gas reservoir

Xiaoliang Zhao [a], Zhenhua Rui [b, *], Xinwei Liao [a], Ronglei Zhang [c]

[a] Department of Petroleum Engineering, China University of Petroleum, Beijing, China
[b] Independent Project Analysis, Inc., USA
[c] Colorado School of Mines, USA

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ABSTRACTS

Fracturing has been identified as a key method for unconventional reservoir development, and it enhances single well productivity and ultimate recovery. Most estimations of fracturing effect are limited to draw boxes around micro-seismic event maps, and add up the 3D volume where micro-seismic events are observed. But the observed volume always is larger which brings error for fracture evaluation. Meanwhile, there is lack of evaluation for the effective permeability, the fracture half-length, the effective stimulated reservoir volume, etc. This paper will present a new method to appraise and diagnose the fracture parameters for shale gas reservoirs qualitatively and quantitatively, which not only can determine the fracture geometry and volume but also determine the fracture parameters, such as effective permeability, fracture half-length, etc. The qualitative evaluation method is combined the relationship table between the fracture geometry and rock brittleness with different pressure response characteristics which can be used to determine the fracture geometry. Then the modern well test analysis method is applied to invert complex fracture parameters for realizing the quantitative evaluation. This method is applied in 3 shale gas wells, and the reasonable interpretation results are achieved with comparison and analysis. The field application results proved that it is a great methodology in shale gas reservoirs. It also can be expanded to other unconventional such as shale gas reservoirs.

1. Introduction

Fracturing is mainly applied in tight reservoir development. It can increase the contact area between reservoir and fracture and shorten the flow distance of oil and gas from matrix to fracture, and realize the reservoir volume reconstruction from three directions (the length, width and height) (Wu et al., 2012, 2011). This technology not only can greatly improve the single well production, also can maximize reservoir producing ratio and ultimate recovery factor.

On 2009, Cipolla proposed that the most critical problems of SRV for shale gas reservoir is how to describe the seepage law from matrix to fracture network, and how to evaluate the fracture density and fracture network conductivity. He also pointed out that the unconventional reservoir after SRV should be divided into stimulated zone and un-stimulated zone to be described (Cipolla et al., 2010). In 2010, Kalantari suggested that the fracture network can be described by the following parameters: fracture distribution and fracture geometry, fracture strike, fracture width. And Discrete fracture network technique cannot be directly applied to actual reservoir simulation which should be turned into double medium model (Cipolla et al., 2009). Arvind proposed that the most important problem is clearly determine the fracture network scope and shape. He put forward a kind of fracturing simulation method (VFMA) to simulate SRV of each fracture section (Kalantari-Dahaghi, 2010). Cipolla derived an unconventional fracture model (UFM) in 2010 which can simulate the intersection between hydraulic fracture and natural fracture. This method need two history matching parameters: conductivities for stimulated area and conductivities for un-stimulated area (Zhou et al., 2012). At the same year, Li suggested that the fracture density, fracture conductivity, non-support fracture conductivity and reservoir stimulated volume can be used to describe complex fracture network (Chaudhary et al., 2011). In 2012, Du divided reservoir into three zones. They are hydraulic fracturing zone, the SRV conduction zone and the SRV trigger zone which are used to describe the different fracture

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* Corresponding author.
E-mail address: zhenhuarui@gmail.com (Z. Rui).

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geometry (Du et al., 2012). At present, the micro-seismic technology is still the main technique for evaluating and descripting fractures after SRV. Micro-seismic monitoring technology can obtain fracture height, fracture length, fracture direction and fracture location. But it is lack of quantitative evaluation of fracture parameters, such as the effective permeability, the fracture half-length, the fracture conductivity, etc. Meanwhile, the coverage area of the micro-seismic interpretation doesn't mean the effective seepage area. Therefore micro-seismic technology can not meet the evaluation need of SRV. It requires a combination of other technology to qualitatively and quantitatively evaluate the complex fracture parameters effectively.

In this study, based on the above researches, combined with the reservoir rock brittleness parameters, the interpretation results of micro seismic and the well test interpretation method, a qualitative and quantitative fracture evaluation method for SRV is proposed.

2. The qualitative evaluation method for fracture after SRV

2.1. The qualitative evaluation method based on rock brittleness parameters

Whether the complex fracture network can be formed or not after SRV mainly depends on the reservoir geological factors. According to the North America shale fracturing treatment experience, it is easy to form fracture network with high rock brittleness, and the fracture tends to be a bi-wing fracture with the reduction of the rock brittleness (Yanyu, 2012). The rock brittleness which affects the fracture mode and extending path strongly depends on the rock mineral composition which further is affected by the relative content of the mediosilicic, quartz, calcium and clay, etc. (Mayerhofer and Lolon, 2009; Buller et al., 2010; Meng and Hou, 2012). For shale rock, lower clay mineral is more brittle. In another way, the higher clay content in shale has stronger plasticity which will lead to plane fracture rather than fracture network (Sun and Tang, 2011). In the US shale gas reservoir, the quartz content is 28%–52%, carbonate content is 4%–16%, and the total brittleness mineral content is 46%–60% (Zou et al., 2010). According to the analysis of the corresponding relationship of the shale mineral composition and hydraulic fracture propagation pattern, 40% brittleness mineral content is the threshold condition to form fracture network.

Along with the lab and field experiment results, Rickman proposed the relationship between rock brittleness and the hydraulic fracture pattern, shown in Table 1 (Rickman et al., 2008). Table 1 classified the SRV fracture pattern into 3 types: bi-wing fracture, fracture network and transition from bi-wing fracture to fracture network. If the rock brittleness is lower than 20%, the rock brittleness is weak and bi-wing fracture is the main pattern; if rock brittleness is greater than 60%, fracture network can be created surround the SRV well, otherwise transition will be formed. This results offer an effective technological support for qualitative evaluation of the SRV fracture pattern.

Micro-seismic interpretation data for three wells after SRV are collected and analyzed to verify the reliability of Table 1. The micro-seismic interpretation results show in Figs. 2–4.

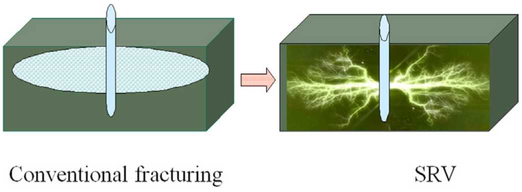

Fig. 1. SRV for vertical well.

For well A, the rock brittleness is 65%. Referring to Table 1, the reservoir around this well should form fracture network after SRV. The micro-seismic interpretation result shows that there is really fracture network which agrees with Table 1(shown in Fig. 2).

For well B and well C, the rock brittleness is 13% and 20% respectively. Referring to Table 1, the reservoir around these two wells should form bi-wing fracture after SRV. The micro-seismic interpretation results show that there is really bi-wing fracture which agrees with Table 1 too (shown in Figs. 3 and 4).

Above examples show that Table 1 has a great reliability and it can be used as a kind of method to determine the fracture geometry after SRV.

2.2. The qualitative evaluation method based on pressure response characters

Different fracture geometry has different seepage mechanism which leads to different pressure response characters. These pressure response characters can be used as one of the qualitative evaluation criteria for fracture geometry.

In this study, the numerical well testing method is adopted to analyze the pressure response character on different fracture geometries. Numerical well testing models are built which includes bi-wing fracture model, fracture network model, transition model between bi-wing fracture and fracture network. These models can be seen in Figs. 5–7.

Fig. 8 shows pressure response characteristics of bi-wing fracture. There are four possible periods: (1) The I period is the early part. The log–log pressure curve and the pressure derivative curve overlap and appear to be a straight line 45° firstly which reflects the characters of stream section. Then a straight line with 1/2 slope for the pressure derivative curve appears which indicates the characters of fracture flow stage. (2) The II period performs as a horizontal line for the pressure derivative curve which is the radial flow character of inner reservoir and the pressure derivative value is 0.5. (3) The III period is controlled by the transition section between inside and outside area. The bending degree relates to the ratio of the pressure coefficient between inside and outside areas. (4) The IV period is the period of the system radial flow. The pressure derivative curve is corresponded with the line of 0.5 M_{12} (the ratio of inner and outer mobility).

Fig. 9 is the type pressure response curves of fracture network. There are five possible periods: (1) the I period is early period which is the pure wellbore storage period. The pressure curve and pressure derivate curve overlap with a straight line of 45°. (2) The II period is cross flow period of matrix and fracture. In this stage, a “dip” occurs in the derivate curve. It is noted that radial flow in the fracture may occur before cross flow period. (3) The III period is radial flow period of inner zone. The pressure derivate curve is a horizontal line, whose value is 0.5. (4) The IV period is transition period of inner zone and outer zone. The bend degree of the pressure derivate curve depends on the ratio of pressure transmitting coefficient. (5) the V period is system radial flow period. The pressure derivative curve is corresponded with the line of 0.5 M_{12} (the ratio of inner and outer mobility).

Fig. 10 is the type pressure response curves of transition model between bi-wing fracture and fracture network. There are five possible periods. (1) the I period is bilinear flow section of early period. The pressure curve and pressure derivate curve appear to be a straight line with a slope of 1/4° which reflect the characters of finite conductivity vertical fractures. (2) the II period is linear flow section of early period. The pressure curve and pressure derivate curve appear to be a straight line with a slope of 1/2° which reflect