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Production performance analysis for composite shale gas reservoir considering multiple transport mechanisms

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ABSTRACT

To better evaluate production performance of shale gas reservoir development, it is urgent to resolve the Stimulated Reservoir Volume (SRV) enigma. However, it is very challenging to characterize the SRV considering multiple transport mechanisms. The SRV is always very complex after fracturing and refracturing. Hence, it is paramount to develop new models to describe SRV and analyze the well performance for shale gas reservoirs. In the paper, we present a dual-region composite reservoir model for multistage fractured horizontal well when developing shale gas. In this model, multiple transport mechanisms were considered including desorption, diffusion, and viscous flow. Then, the model solution and its validation against other semi-analytical model results were presented. Different flow regimes were divided according to pressure transient analysis curves. Sensitivity studies to quantify the key parameters affecting the well performance were performed finally. Seven variables, which are Langmuir volume, Langmuir pressure, diffusion coefficient, inner region radius, inner region permeability, stress sensitivity coefficient, and hydraulic fracture conductivity, were investigated. The model proposed here is more comprehensive by considering not only SRV but also the transport mechanisms of shale gas, and can be used for performance analysis in shale gas reservoir development.

1. Introduction

Shale gas as an unconventional gas resource (Yu, 2015) has emerged as an important energy source worldwide over the last several decades and is gradually becoming a key component in the world's energy supply (Guo et al., 2015; Wang and Krupnick, 2013). Taking the U.S. as an example, by the end of the year 2013, the proved reserve is 159,115 billion cubic feet which accounts for about 44.9% of the United States' domestic natural gas reserves. The estimated production is 11,415 billion cubic feet which accounts for about 43.3% of the United States' domestic natural gas production (Source: http://www.eia.gov/dnav/ng/ng_enr_shalegas_a_EPG0_R5301_Bcf_a.htm).

Due to extremely low permeability and porosity of shale gas reservoir, multistage hydraulic fracturing has become an integral tool in shale gas development. The economic feasibility of shale gas reservoirs has a strong relationship with the fracture system permeability near the wellbore. Considered to be the most effective way to produce shale gas, multistage fractured horizontal well can create several high-conductivity hydraulic fractures as flow paths, at the same time, activate and connect existing natural fractures so as to develop large fracture network system (Clarkson, 2013). The zone containing the main high-conductivity hydraulic fractures and large spatial network system which can effectively improve well performance is defined as SRV (stimulated reservoir volume), and the remaining zone which hardly influenced by the treatment of hydraulic fracturing is similarly defined as USRV (un-stimulated reservoir volume) (Ozkan et al., 2009, 2011; Stalgorova and Mattar, 2012a, 2012b; Mayerhofer et al., 2006).

According to Javadpour et al. (2007, Javadpour, 2009), shale gas reservoir has complex pore structure, multi-scale pore size and unique storage properties, causing shale gas to migrate through the pore by multiple flow mechanisms including desorption from the kerogen walls, diffusion from the kerogen bulk to the surface and viscous flow in natural fractures. Kucuk and Sawyer (1980) first used analytical method and numerical method to study the pressure transient behavior of shale gas reservoirs. However, both of them ignored the effect of diffusive flow. Carlson and Mercer (1991)

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described desorption behavior of shale gas by Langmuir isotherm theory and employed the Fick's law to consider the effect of diffusion. However, pressure responses calculated by this model could not reflect characteristic flow regime for fractured wells. Considering the diffusive flow mechanism, Ozkan et al. (2010) presented the dual-porosity multiply fractured horizontal well model for shale gas reservoir,. However, this paper ignored the adsorption gas which may cause great effect on shale gas production performance. Freeman et al. (2013) and Cheng (2011) studied the pressure transient behaviors of multistage fractured horizontal wells in shale gas reservoir with a numerical simulation method and briefly discussed the effect of gas desorption, but the diffusion in shale matrix was not taken into account.

Up to now, many models have been established to study the transient flow behavior of multiple fractured horizontal well for both conventional and unconventional oil/gas resource. Larsen and Hegre (1991, 1994) derived analytical solutions to describe the pressure transient behaviors for horizontal wells with transverse fractures. Raghavan et al. (1994) discussed the effects of hydraulic fracture parameters, such as fracture number, location, and orientation, on pressure transient responses. Crosby et al. (2002) and Wan and Aziz (2002) respectively described the pressure response characteristics when fractures rotated at any angle to the horizontal well with corresponding semi-analytical solutions. Using the numerical and analytical methods, Al-Kobaisi et al. (2006) shows the pressure transient behavior for finite conductivity. Aboaba and Cheng (2010) analyzed early linear flow dominated data to estimate both fracture half-length and formation permeability in shale gas reservoir. Bello and Wattenbarger (2010) identified five flow regions to approximate the shale gas completions and presented the pressure transient behavior. Medeiros et al. (2008) proposed a semi-analytical method to study the performance of fractured horizontal well in unconventional gas reservoirs. Al Rbeawi and Tiab (2013) presented new analytical models to analyze the pressure behavior for a horizontal well with multiple-shape hydraulic fractures. Yao et al. (2013) used Green's functions to analyze the pressure transient responses for MsFHW and studied the characteristic response by varying relevant parameters. Zhao et al. (2013) used the "triple porosity" model to study the transient pressure behaviors of the MFH well in shale gas reservoir. These models above are simple to solve, however, they did not take into account the effects of desorption and diffusion which are important migration mechanisms in shale.

To describe the pressure transient response more accurately, Guo et al. (2012) proposed improved dual-mechanism dual-porosity model to interpret pressure signals considering multiple flows in shale gas. Wang (2014) presented the well-test model of MsFHW for shale gas which takes more mechanisms into account, such as desorption, diffusive flow and viscous flow. Although the above researchers have made much works on transient pressure analysis of MsFHW well, the models they proposed did not consider the effect of the stimulated reservoir volume (SRV).

In order to concisely describe the fracture network (natural or induced) around the hydraulic fractures, Ozkan et al. (2011) presented the effective trilinear flow model where drainage volume between fractures called stimulated reservoir volume to calculate the performance of MsFHW. Brown et al. (2011) gave the analytical trilinear flow model considering fluid exchange among various reservoir components to study the pressure transient and rate behavior in unconventional shale reservoirs. Stalgorova and Mattar (2012a, b) improved the trilinear-flow model to a five regions flow model to simulate both the stimulated reservoir volume and the regions beyond fractures. Zhao et al. (2014) extended the homogenous MsFHW into a composite shale gas reservoir model and described the SRV as the inner region. The effects of related parameters were analyzed. But the model did not consider some key flow mechanisms for shale gas. Sang et al. (2014) presented an improved trilinear model for productivity prediction of volume fractured horizontal wells considering desorption and adsorption process. The SRV is always very complex after fracturing and refracturing. The work resolving the Stimulated Reservoir Volume (SRV) enigma will go on.

In this paper, the dual-region dual-porosity composite reservoir model for MsFHW with stimulated reservoir volume was presented. In the model, desorption and diffusion flow were considered in shale matrix. Transient diffusion in shale matrix was used. The rest of the article is structured as follows: Section 2 will introduce the simplified assumptions on physical properties of the shale gas reservoir and establish the mathematical model by considering not only SRV but also several flow mechanisms of shale gas. Section 3 will verify this new model. In the end, different flow regimes are divided and the effects of related parameters are analyzed.

2. Mathematical model

2.1. Physical model

The schematic diagram for MsFHW with SRV is shown in Fig. 1. The MsFHW model is shown in Fig. 2. The reservoir has two

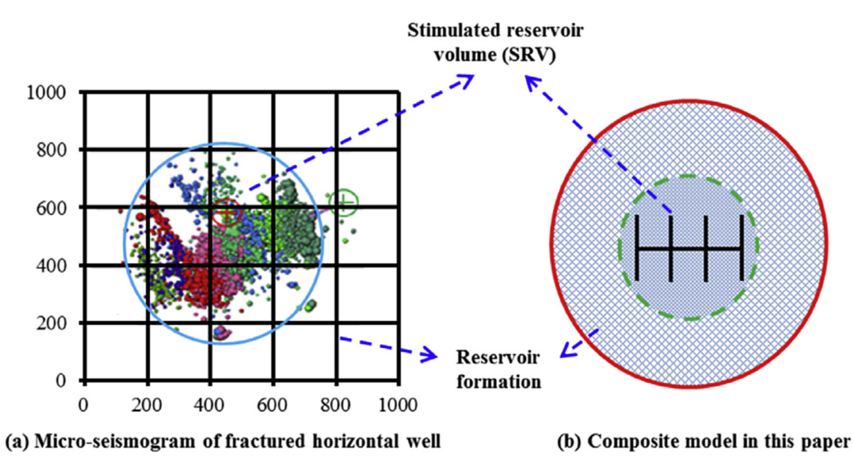

Fig. 1. Multistage fractured horizontal well with SRV.