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Semi-analytical model of the transient pressure behavior of complex fracture networks in tight oil reservoirs

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A B S T R A C T

Unconventional resources have been successfully exploited with technological advancements in horizontal drilling and multi-stage hydraulic fracturing, especially in North America. Due to pre-existing natural fractures and the presence of stress isotropy, several complex fracture networks can be generated during fracturing operations in unconventional reservoirs.

Based on Ozkan's plane source function, by virtue of equivalent conversion and coordinate transformation, a new plane source function was derived that can handle the fluid flow behavior in an inclined fracture in dual media, anisotropic, tight oil reservoir. Using the superimposing method, a semi-analytical model was established to analyze the transient pressure behavior of horizontal wells with complex fracture networks. Using this method, we defined five flow regimes: Linear flow, fractures interference flow, first radial flow, cross flow andpseudo-radial flow. The influences of some of the critical parameters on the transient pressure behavior were studied, including the fracture number, distribution of the fractures, storage ratio, and so on.

This paper provides a useful tool for reservoir engineers regarding fracture design as well as for estimating the performance of horizontal wells with complex fracture networks.

1. Introduction

Technological advancements in horizontal drilling and multi-stage hydraulic fracturing have stimulated a boom in unconventional resource generation throughout the world, especially in North America. Because of the presence of stress isotropy and pre-existing natural fractures, complicated fracture networks can be created in tight oil reservoirs when conducting stimulation treatments (Fisher et al., 2002; Maxwell et al., 2002). Knowledge of the fluid flow behavior in these complex fracture networks is essential information to evaluate the performance and effectiveness of the stimulation.

Several models have previously been established to predict the behavior of fracture networks in tight oil reservoirs in the last few years. These models can be divided into three categories. The first category reviewed here is the analytical method. Based on El-Banbi and Wattenbarger (1998) linear model, Bello and Wattenbarger (2009) established a dual linear model to simulate the behavior of transient pressure of horizontal wells with multi-stage fractures. As shown in Fig. 1 a, the reservoir is composed of slab matrixs and hydraulic fractures. The arrows indicate the flow directions, and the bisector of the distance between two hydraulic fractures is a no-flow boundary (the no-flow boundary is labeled by a red dash line in Fig. 1). Ahmadi et al. (2010) extended Bello's dual linear model to a triple linear model (As shown in Fig. 1b). There are two fracture systems comparing with Bello's model. Assuming that fluids flow linearly from the matrix to microfractures and then to macrofractures. Brown et al. (2011) also presented a triple-linear model (the schematic is shown as Fig. 1c). The reservoir was

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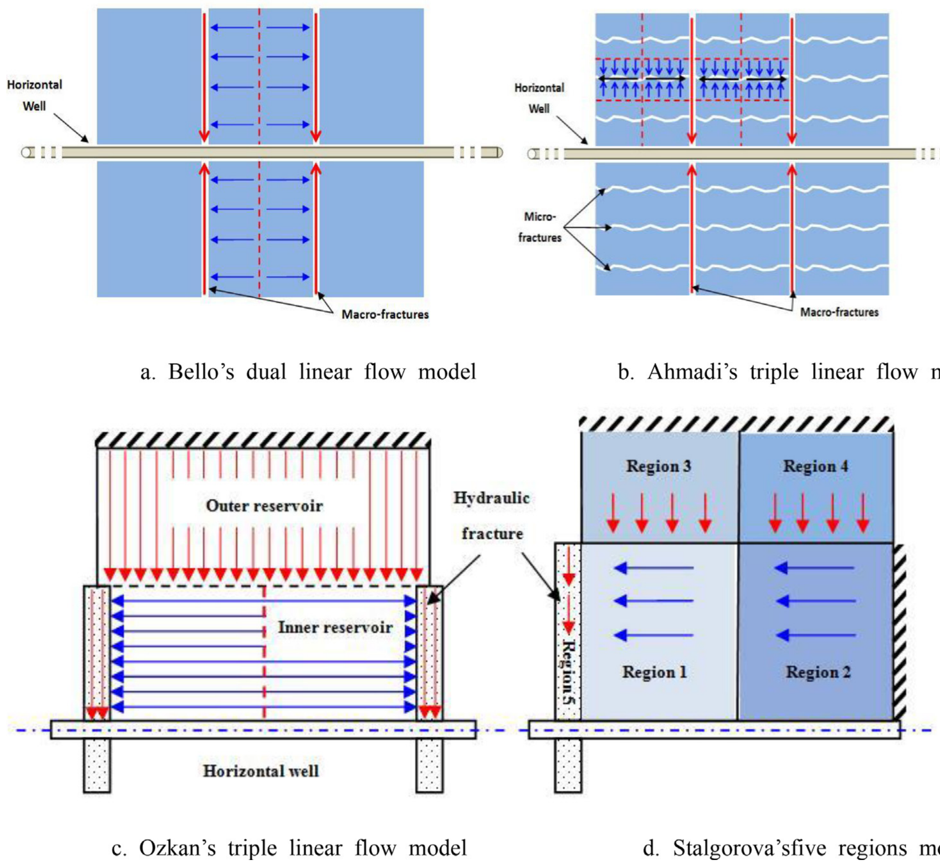

a. Bello's dual linear flow model

b. Ahmadi's triple linear flow model

c. Ozkan's triple linear flow model

d. Stalgorova'sfive regions model

Fig. 1. Schematic of analytical methods.

divided into three sections: The outer reservoir, inner section and hydraulic fracture, and the flow in each section was assumed to be linear. Stalgorova and Mattar (2013) extended Brown's trilinear flow model to five regions model for more complex reservoirs (the schematic is shown as Fig. 1d). They formulated the 1D flow solutions for each region and then coupled them by imposing flux and pressure continuity across the boundaries between the regions. Based on the three regions flow model or five regions flow model, several works (Leng et al., 2014; Zhang et al., 2016) established many linear flow models for unconventional reservoirs (containing shale gas, tight oil and tight gas resources). These analytic models have provided a comprehensive insight into the performance of fracture networks and have provided practical tools to evaluate stimulation effectiveness. However, all of these models assumed that all of the fractures have the same length and equal conductivity and are spaced uniformly along the horizontal well. As we all known the actual fracture network is very complex and this assumption is too ideal to capture the details of the real fracture networks, such as the irregular spatial distribution and complex interconnected scenarios of the fractures.

The second category is the semi-analytical model which was developed using the source function method. Zhou (2012) developed a semi-analytical method to simulate production from a complex fracture network. In this model, each fracture in the network was treated explicitly. This is the biggest advantage of the semi-analytical model over analytical models. However, his model was based on conventional reservoirs and is not suitable for dual media anisotropic tight oil reservoirs. Based on Ozkan's (1988) plane source function, Luo and Tang (2014) established a transient pressure behavior model for multi-wing fractures connected to a vertical wellbore. The vertical well was fractured with multiple fracture wings that varied the intersecting angle and length of each fracture. This model cannot handle the transient pressure behavior of horizontal wells with complex fracture networks in anisotropic tight oil reservoirs. Using Ozkan's plane source function, other scholars (Pin et al., 2015; Chen et al., 2015) also established transient pressure behavior models for complex fracture networks. In these models, the complex fracture networks can be divided into a proper number of segments. This approach allows one to focus on a detailed description of the discrepancy in the complex network. Yet, all of these semi-analytical models have a common limitation. They all assume that the reservoir is isotropic ($kx = ky = kz$), which it is too ideal.

The third category is numerical simulations, in which hydraulic and natural fractures are generally represented by high permeability refined grids (Palagi and Aziz, 1994; Skoreyko and Peter, 2003; Li et al., 2003; Ali and Sheng, 2015; Wan et al., 2016). Based on a structured grid system in conventional numerical simulators, Mayerhofer et al. (2010), Warpinski et al. (2008) and Cipolla (2009, 2010) simulated the production of orthogonal networks in shale gas reservoirs. These works qualitatively analyzed how the size and density, fracture conductivity, matrix permeability and gaps in the fracture networks affected the horizontal well productivity. However, these models assumed that all of the hydraulic fractures are orthogonal with natural fractures, and also cannot rigorously capture the details of the fracture network characteristics, such as the irregular spatial distribution, complex interconnected scenarios, and so on. Besides, the numerical methods are time-consuming and have inherent uncertainties that could cause them to be less accurate.