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Production performance of horizontal wells with dendritic-like hydraulic fractures in tight gas reservoirs

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ABSTRACT

Nowadays horizontal wells, combined with hydraulic fracturing technology, have been widely used to produce tight gas at an economic rate. The production performance of the horizontal well can be predicted by analytical or numerical models. In most models, the horizontal wells are assumed to be fractured by bi-wing fractures. However, recent micro-seismic measurements depict a dendritic-like morphology of hydraulic fractures in tight gas reservoirs. This indicates the conventional fracture models are sometimes inapplicable for tight gas simulation.

In this paper, a modified off-center well model was coupled in the discrete fracture model (DFM) to predict the production performance of dendritic-like stimulated horizontal wells. Finite volume method was used to discretize the partial differential equations, and the linearized equation system was solved iteratively in a fully implicit scheme. The off-center well model was verified against ECLIPSE. A field case of multi-stage fractured horizontal well from a shale gas reservoir was studied.

In addition, the effects of some fracture geometric parameters (e.g., fracture angle, fracture asymmetry and fracture branch number) on well production were investigated in detail. Results show that fracture angle has high relevance to the production performance in that cumulative production tends to be higher with more evenly distributed angles. Fracture asymmetry seems to have little influence upon the production. Fracture branch number has a strong influence on enhancing gas production, but the influence becomes weaker with increasing branch number. This paper provides us a better understanding of dendritic-like fractured gas reservoirs.

1. Introduction

Tight gas resource has drawn great attention for its substantial reserve and an increasing demand of energy in the past decades. By using horizontal well and hydraulic fracturing techniques, the industry has achieved economic exploitation of tight gas reservoirs. In field practice, horizontal well is usually drilled parallel to the minimum stress direction, and expected to create bi-wing fractures. In the framework of this bi-wing fracture model, many numerical and analytical studies were performed (e.g., Chen and Raghavan, 1996; Meyer et al., 2010; Clarkson and Beierle, 2011; Song and Ehlig-Economides, 2011; Yu et al., 2014), to design, assess and forecast the stimulation activities.

In fact, fractures are not always in bi-wing shape. Complex network geometry could be induced by faults, pre-existing natural fractures and large stress bias, etc. (Warpinski et al., 2009). Laboratory experiments and outcrop observations (Germanovich et al., 1997) also demonstrated a multiple overlapping phenomenon in hydraulic fractures. Recently, a complexity of dendritic-like fracture geometry was observed in both oil and gas fields through micro-seismic mapping technique (Fig. 1). Some researchers established analytical models to study the productivity and transient response of dendritic-like stimulated oil wells (Craig and Blasingame, 2006; Chen et al., 2014; Luo and Tang, 2015). Unfortunately, these models can't apply to gas wells since the micro-pore mechanism (Klinkenberg, 1941) and strong compressibility of gas are not considered in them..

Compared to analytical methods, numerical methods have advantages in handling non-linear physical properties (e.g., Klinkenberg effect, highly compressible fluid properties) and complex fracture network (Jiang and Younis, 2015). However, an important challenge in numerical simulation is computation efficiency. Traditionally, local grid refinement is adopted around fractures for accurate simulation (Yu et al., 2014). As a result, field cases with numerous hydraulic fractures would cost too much CPU time. Some conceptual models were

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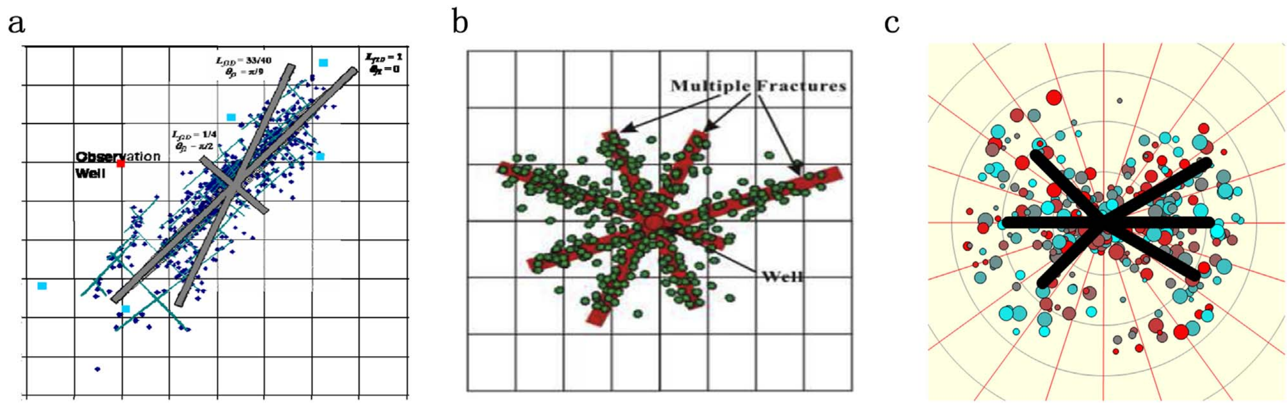

Fig. 1. Micro-seismic images: (a) A multiple fracture model for incompressible fluid based on Barnett shale micro-seismic image (Craig and Blasingame, 2006). (b) Multiple fractures around a vertical well with SRV treatment in Chinese oilfield (Chen et al., 2014). (c) Hydraulic fractures near a horizontal well in a shale gas reservoir.

introduced to promote the efficiency of fracture simulation: dual-porosity model and DFM. The dual-porosity model assumes two systems, i.e., the matrix and the fracture. Herein, transfer function (Arbogast, et al., 1990; Geiger et al., 2013) is coupled to connect matrix with fracture. However, the calculation of transfer function remains a problem with complex fracture network.

In comparison, DFM is making progress in fracture simulation. DFM describes real fracture network explicitly with independent permeability and porosity. Besides, the elimination of fracture intersections (Karimi-Fard et al., 2003) could improve the stability of the simulator at a longer time-step. There has been some works on DFM to handle flow around fracture network. Zhao et al. (2011) coupled geo-mechanical modeling in multiphase flow to investigate water block in shale gas reservoir. Moinfar et al. (2013) established a hybrid model, which used DFM for large-scale fractures and dual continuum model (DCM) for small-scale fractures. His method further improved the computation capacity of the simulator. Mi et al. (2014a, b) investigated impacts of diffusion type and fracture aperture on shale gas dynamics using DFM. Norbeck et al. (2014) presented an integrated DFM model to study physical processes such as fluid flow, fracture deformation and fracture propagation in fractured reservoirs. Although these studies considered the interactions between fracture networks, they didn't address well treatment when horizontal wells are intersected by multi-wing hydraulic fractures.

Well treatment is usually realized through analytical well models. Peaceman (1983) developed the most widely used well model when the trajectory of the well intercepts block center. For wells not located in block center, some off-center models (Williamson and Chappelear, 1981; Ding and Renard, 1994; Su, 1995) were proposed. In this paper, we incorporated an off-center well model into discrete fracture modeling. Pressure dependent matrix permeability was considered to account for micro-pore flow mechanism. Finite volume method and fully implicit scheme were applied to solve the mathematical model. Reliability of the modified off-center well model was validated by the commercial simulator ECLIPSE and field data. Eventually, several sensitivity studies were conducted to understand well and reservoir dynamics with varying fracture angle, fracture asymmetry and fracture branch number.

2. Physical model

As mentioned above, in tight gas reservoirs, hydraulic fractures might be dendritic-like due to complicated reasons. Fig. 2 is a schematic of a horizontal well intersected by dendritic-like hydraulic fractures. Different from the conventional symmetrical bi-wing fracture, the dendritic-like fractures have multiple wings with independent permeability and porosity. Fracture interference occurs early and makes pressure gradient geometries complicated (Chen et al., 2014). To further study the influences of dendritic-like geometry on gas well dynamics, the following assumptions are made:

(1) Single phase gas (methane) flows through isothermal, incompressible and single layer reservoir, and the gravity effect is ignored.
(2) Gas production from the matrix to the horizontal well is not considered.
(3) In each dendritic-like geometry, several parallel plate fractures intersect at a straight line, and penetrate the reservoir with a height of the reservoir thickness.
(4) Fracture conductivities are in similar level to result in similar pressure draw-down, making fracture-fracture flow at the intersection line negligible.

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3. Mathematical model

In this section, we presented the governing equations of DFM and then discussed well treatment of the multi-wing well.

3.1. Governing equations of DFM

A main idea of the discrete fracture model (DFM) is to use (n-1) dimensional entities to represent fractures in an n-dimensional space (Karimi-Fard et al., 2003; Monteagudo and Firoozabadi, 2004; Hoteit and Firoozabadi, 2008; Sandve et al., 2012; Zidane and Firoozabadi, 2014). For example, fractures are represented using 1D segments in 2D space, and using 2D rectangles in 3D space. This approach simplifies unstructured grid generation and requires separated governing equations for the matrix and the fracture in dimension. In 2D space, the governing equations were given as follows:

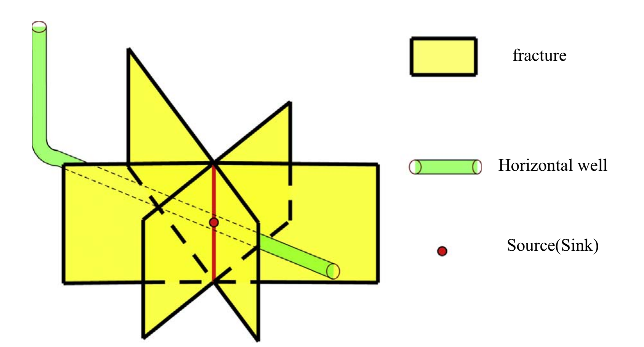

Fig. 2. Schematic of a horizontal well intersected by dendritic-like hydraulic fractures.