ARTICLE IN PRESS

Journal of Petroleum Science and Engineering (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Analytical model to simulate production of tight reservoirs with discrete fracture network using multi-linear flow

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ARTICLE INFO

Keywords:
Stimulated reservoir volume
Tight reservoirs
Multi-linear flow model
Production performance analysis

ABSTRACT

A common way to produce hydrocarbons from tight reservoirs is to use volume fracturing. After volume fracturing, the stimulated reservoir volume (SRV) always exists around the wellbore. To characterize the SRV, many work have been done using simulation methods. The Discrete Fracture Network (DFN) model is one of the commonly used simulation methods. Based on the simulated results of DFN model, this paper constructed a multi-linear flow model to analyze the pressure transient and rate transient behaviors in tight oil reservoirs with SRV, where the reservoir is divided into many regions including matrix system outside the fracture network, matrix system inside the fracture network, fracture network system. We formulates the 1-D flow solutions for each region, and then couple them by imposing flux and pressure continuity across the boundaries between regions. We solve the model with the linear flow model and using Laplace transform and Stehfest algorithm comprehensively. The model solution is verified with numerical simulation thoroughly. And we test the model with field cases to analyze fractured well performance in tight oil reservoir. History matching results are shown according to real production data. Sensitivity studies to quantify the key parameters affecting the well performance were performed finally. Five variables, which are fracture spacing, fracture network size, fracture network conductivity, matrix permeability and reservoir size, were investigated. The presented new model and obtained results can enrich the production performance analysis methods for tight oil reservoirs.

1. Introduction

In recent years, development of tight reservoirs has become a hot issue due to shortage of conventional resources. The huge amount of tight resources can satisfy the urgent need for energy consumption around the world. Mayerhofer et al. (2006) firstly proposed the onception of SRV using micro-seismic techniques during the study of hydraulic fracture change of Bantt shale, which was different from conventional double wings symmetric fractures. Horizontal well and multistage hydraulic fracturing could not only create high conductivity flow paths, but also activate and connect existing natural fractures to generate large fracture networks (Clarkson, 2013). To characterize the SRV, many work have been done using experimental (Jeffrey et al., 2009; Guo et al., 2014b, 2015) or simulation methods (Xu et al., 2010; Cipolla et al., 2011; Cipolla et al., 2010; Meyer and Bazan, 2011; Weng et al., 2014, 2015). The Discrete Fracture Network (DFN) model is one of the commonly used simulation methods. To characterize the SRV, many DFN simulation works have been done to study the natural fracture network impacts on production performance.

The purpose of SRV characterization is to analyze and predict the production performance of reservoir development and then to guide us to make reasonable production plans. In general, there are two kinds of methods for SRV production performance analysis: simulation methods and analytical/semianalytical methods.

Simulation methods can simuate depletion from a complex, heterogeneous and naturally fractured reservoir. Mayerhofer et al. (2006) and Warpinski et al. (2009) conducted a parametric study by building an orthogonal fracture network model with uniform conductivity to illustrate the effect of fracture network size, density, and conductivity on horizontal well productivity. Cipolla et al. (2008) built two kinds of reservoir models that employ complex fracture network. One model assume uniform fracture conductivity throughout fracture networks based on the assumption of even proppant distribution in the network. The other model assumes that proppants would be concentrated in the primary fracture, leading to infinite conductivity for the primary fracture. Ming Gu et al. (2015) Conducted a parametric study for well productivity response to fracture conductivity in naturally fractured reservoirs. And natural fracture conductivity and intensity, martrix

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http://dx.doi.org/10.1016/j.petrol.2017.01.007
Received 17 July 2016; Received in revised form 17 November 2016; Accepted 4 January 2017
0920-4105/

Nomenclature

h	Thickness of reservoir, m
p_i	Original pressure of reservoir, MPa
p_f	Pressure of fracture, MPa
μ	Viscosity of reservoir fluid, mPa·s
Q	Prodcution rate, m^3/d
B	Volume factor of reservoir fluid, dimensionless
p	Pressure of reservoir, MPa
p_{wf}	Bottom hole pressure, MPa
L_x	Fracture spacing in x axis, m
L_y	Fracture spacing in y axis, m
C_t	Comprehensive compressibility, 1/MPa
K	Matrix permeability, m^2
ϕ	Matrix porosity, dimensionless
K_f	Fracture permeability, m^2
W_f	Fracture width, m
ϕ_f	Porosity of fracture (proppant), dimensionless
C_{ft}	Comprehensive compressibility of fracture, 1/MPa
Q_1	Production rate of fracture 1, m^3/d
Q_2	Production rate of fracture 11, m^3/d
y_{wm}	The length of matrix system outside the fracture network in y-direction
x_{wm}	The length of matrix system outside the fracture network in x-direction

Superscript

$\_$	Laplace domain

Subscripts

D	Dimensionless
f	Fracture system
$f(m)(n)D$	Dimensionless parameters of fracture $(m)(n)$
$(m)(n)D$	Dimensionless parameters of matrix $(m)(n)$
y_{wm}	The length of matrix system outside the fracture network in y-direction
x_{wm}	The length of matrix system outside the fracture network in x-direction

permeability, water production, hydraulic fracture spacing, and flowing bottomhole pressure on critical conductivity are investigated.

Due to the computational efficiency, analytical/semi-analytical methods have been widely studied. Many "composite model" have been proposed for pressure/rate performance analysis when considering SRV in tight reservoir development. Among the analytical/semi-analytical methods, the most popular one is the "linear flow" model. Ozkan et al. (2009) proposed the "trilinear flow model" which includes the hydraulic fracture, inner region, and outer region. The basic assumption of this model is the ultra-low permeability of the tight formation. After that, they improved the model and used it to analyze real field data (Brown et al., 2011; Ozcan et al., 2014). Stalgorova and Mattar (2012a, 2012b) extended the "trilinear flow model" to "five region model" in which the formation is partially stimulated by the fracturing between two adjacent fractures. Tian et al. (2014) used the "trilinear flow model" to analyze well test performance for shale gas reservoirs considering dual diffusion in matrix. Another method to characterize SRV is to use circular composite model. The basic assumption is that the SRV has a circle shape around the wellbore. Zhao et al. (2014) used the inner circle region to characterize the SRV and the performance of multi-fractured horizontal well was analyzed for tight gas reservoirs. Jiang et al. (2014) showed the rate decline analysis results for tight oil reservoirs using point source method. Another method to characterize the SRV is to consider the SRV as an ellipse shape (Xu et al., 2015; Xie et al., 2015; Siripatrachai et al., 2014; Rana, 2011) or a rectangular region (Dongyan et al., 2015). Obut and Ertekin (1984) first used the elliptical flow to study the well testing methods in composite system. They obtained the "approximate solution" for wellbore pressure analysis. Based on this, Ketineni (2012) established the composite model for multi-stage hydraulically fractured horizontal well in a naturally fractured reservoir considering SRV. They considered the SRV as a "rubble zone" and they assumed a pseudo-steady model to describe the transfer of the fluid from matrix to fracture. They have a simple assumption about the SRV, and there have a big difference between the real fracture networks and the assumption model.

In order to make the description of Discrete Fracture Network more accurate, it is necessary to use a finer grid when using commercial flow method, which will greatly increase the computational amount (time consumption). It is can be seen from the references in this paper that the SRV was described with dual porosity model or considered as a higher permeability matrix in the current semi-analytical methods. So the details of the SRV are ignored. The Discrete Fracture Network (DFN) model is one of the commonly used simulation methods and there is no corresponding semi-analytical model to analyze it's performance.

In order to describe the fracture networks more accurately, this paper built a multi-linear flow model based on the DFN model (Jacot et al., 2010; Xu et al., 2010; Meyer and Bazan, 2011). Firstly, the physical model of multi-linear flow is established, and the fluid flow pattern of the matrix system inside the fracture network area is discussed. Secondly, a mathematical model is proposed, and then the analytical solution is derived by using the Laplace transform method. Thirdly, Stehfest numerical inversion algorithm is used for numerical calculation, and the numerical calculation method and steps are presented. Finally, the accuracy verification and field case are carried out. Sensitivity studies to quantify the key parameters affecting the well performance were performed finally. Five variables, which are fracture spacing, fracture network size, fracture network conductivity, matrix permeability and reservoir size, were investigated.

2. Model construction

In this section, we discussed the physical and mathematical models for understanding DFN production performance.

2.1. Physical model

The schematic diagrams of DFN is shown in Fig. 1. (Meyer and Bazan, 2011). Seen from Fig. 1, the fracture network system is

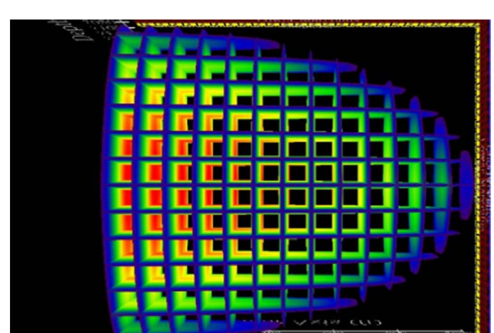

Fig. 1. DNF 3D aerial view (x-y plane).