Journal of Natural Gas Science and Engineering 21 (2014) 283–295

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

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

Well testing model for multi-fractured horizontal well for shale gas reservoirs with consideration of dual diffusion in matrix

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ARTICLE INFO

Article history:
Received 15 May 2014
Received in revised form
1 August 2014
Accepted 1 August 2014
Available online

Keywords:
Shale gas
Multi-stage fractured horizontal well
Productivity model
Desorption
Dual diffusion
Type curve

ABSTRACT

Shale gas reservoir is typical unconventional reservoir, it's necessary to take advantage of multi-stage fractured horizontal well so as to develop those kinds of reservoirs, which can form high conductivity hydraulic fractures and activate natural fractures. Due to the existence of concentration gap between matrix and fractures, desorption gas can simultaneously diffuse into the natural fractures and hydraulic fractures. This process can be called dual diffusion. Based on the triple-porosity cubic model, this paper establishes a new well testing model of multi-stage fractured horizontal well in shale gas reservoir with consideration of the unique mechanisms of desorption and dual diffusion in matrix. Laplace transformation is employed to solve this new model. The pseudo pressure transient responses are inverted into real time space with stehfest numerical inversion algorithm. Type curves are plotted, and different flow regimes in shale gas reservoirs are identified and the effects of relevant parameters are analyzed as well. Considering the mechanism of dual diffusion in matrix, the flow can be divided into five regimes: early linear flow; pseudo-steady state inter-porosity flow; the diffusion from matrix into micro-fractures; the diffusion from matrix into hydraulic fractures and boundary-dominated flow. There are large distinctions of pressure response between pseudo steady state diffusion and unsteady state diffusion under different value of pore volume ratio. It's similar to the feature of pseudo-steady state inter-porosity flow, diffusion coefficient and Langmuir parameters reflect the characters of pseudo-steady state diffusion. The numbers of stage of hydraulic fractures have certain impact on the shape factor of matrix and the inter-porosity coefficient. This new model is validated compared with some existing models. Finally, coupled with an application, this mew model can be approximately reliable and make some more precise productivity prediction.

0. Introduction

Shale gas reservoir is typical unconventional reservoirs due to its ultra-low permeability and porosity. Generally speaking, there is no natural productivity capacity for those kinds of reservoirs. Multi-stage fractured horizontal well currently has been proved to be the most effective way to produce shale gas, and this method can not only create several high-conductivity hydraulic fractures, but also activate and connect existing natural fractures so as to form large spatial 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).

At present, large number of scholars have done large amount of researches about transient pressure analysis for shale gas, some analytical and semi-analytical solutions are developed as well. Shale gas reservoir is the classical naturally fractured reservoir (NFR) which contains complex natural fractures and matrix. In terms of this kinds of reservoirs, Barenblatt et al. (1960), Warren and Root (1963) originally proposed the dual-porosity model which assumed pseudo steady state fluid transferred between matrix and fractures, and then Kazemi (1969), De Swaan (1976) and Ozkan et al. (1987) developed some other dual-porosity models for shale gas reservoirs to enrich the former productivity model, which all assumed unsteady-state (transient) flow condition between

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http://dx.doi.org/10.1016/j.jngse.2014.08.001
1875-5100/

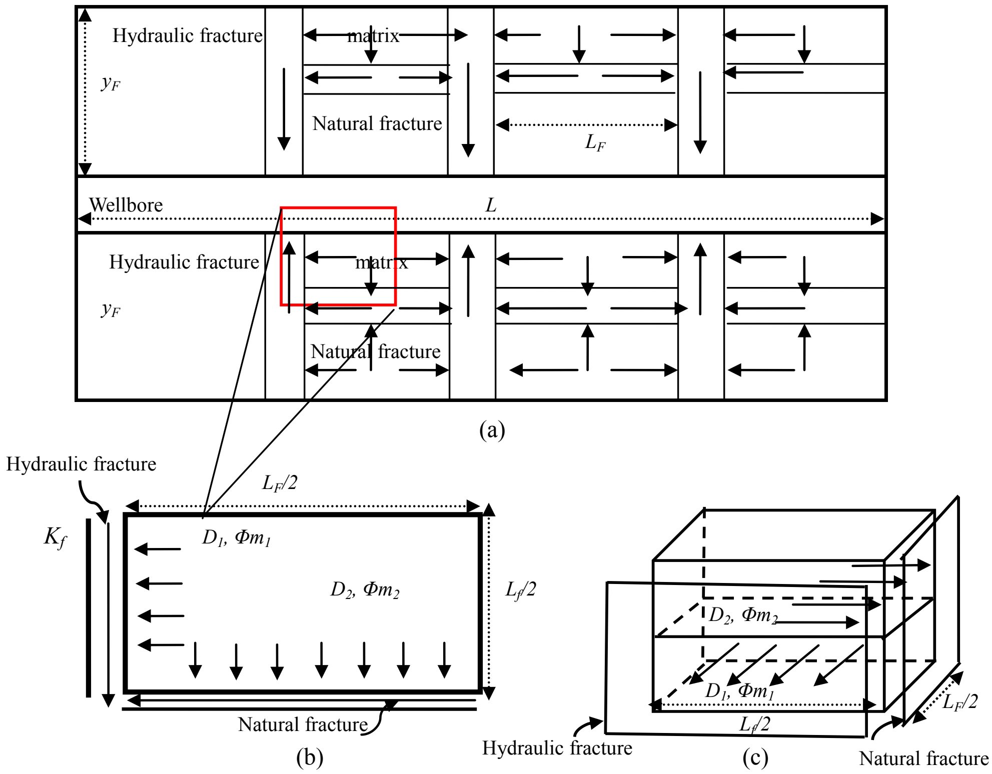

Fig. 1. An ideal physical model of multi-stage fractured horizontal well.

matrix and fractures. However, all of these dual-porosity models neglected the diffusion and adsorption phenomenon on shale gas reservoirs.

Some scholars investigated a large amount of production data from field and found that these dual-porosity models may not be true in actual reservoirs. An improvement to overcome this drawback is to considerate two different fracture systems with different properties. This system is so-called triple-porosity system. Al-Ghamdi and Ershaghi (1996) initiatively proposed the dual fracture triple-porosity model for radial flow, and then Liu et al. (2003), Wu et al. (2004) and Dreier (2004) enriched the triple-porosity models, unfortunately, these models still did not considerate the impact of adsorption and diffusion. It is common to find that the linear flow stage is apparently identified in some real productivity curves, especially for these fractured reservoirs, therefore, the linear flow models for shale gas are proposed by some scholars. El-Banbi (1998) proposed a linear dual-porosity model in linear fractured reservoirs, and originally derived the solutions in Laplace space, but the impacts of desorption and diffusion on the production were still ignored; Hasan and Al-Ahmadi and Wattenbarger (2011) proposed a triple-porosity linear flow model with consideration of the impact of shale gas desorption, however, the diffusion in matrix is neglected; Zhang et al (2013) proposed triple-porosity spherical flow model for the fractured infinite shale gas reservoirs which considered the impact of diffusion and desorption, however, they considered hydraulic fractures as infinite conductivity, besides, this model was not suitable to some kinds of reservoirs treated with stimulated reservoir volume fracturing. Ezulike Daniel Obinna and Dehghanpour Hassan (2014) first proposed the triple-porosity dual interporosity linear flow model, that is to say, the gas simultaneously depletes from matrix into natural fracture and hydraulic fracture, however, the desorption and diffusion were ignored as well.

In view of this, at the present time, there are so many linear triple-porosity models for multi-stage fractured horizontal wells with consideration of single diffusion in matrix, however, the mechanism of dual diffusion in matrix is a new concept and domain. In terms of some real field cases, we often can hardly identify its real flow mechanisms. Therefore, it is necessary to establish a new relevant model with consideration of dual diffusion in matrix to deal with this problem. This paper simplifies the SRV zone as linear triple-porosity cubic model, comprehensively taking various mechanisms into account, such as adsorption and dual diffusion in shale matrix, viscous flow in fractures. Besides, we assume the gas simultaneously diffuses from the matrix into natural fractures and hydraulic fractures in SRV zone. Laplace transformation is employed to solve this new model. The pseudo pressure transient responses are inverted into real time space with stehfest numerical inversion algorithm Stehfest (1970). Type curves are plotted, and different flow regimes in shale gas reservoirs are identified and the effects of relevant parameters are analyzed as well. This new model is validated compared with some existing models proposed by Zhao et al. (2013) and Hai-Tao Wang (2014). Finally, coupled with a field application, this mew model can be approximately reliable and make some more precise productivity prediction.

1. Production model

1.1. Conceptual model

The schematic illustration in Fig. 1a shows a fully penetrating multi-stage fracturing horizontal well. The multi-stage fracturing shale gas reservoir is ideally simplified as triple-porosity cubic model, and the horizontal well is located in the center of a closed rectangular formation.

For the analysis of dual diffusion in matrix, the matrix is artificially divided into two virtual sections which feed hydraulic fracture and natural fracture respectively via diffusion. This method can