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Numerical simulation of gas transport mechanisms in tight shale gas reservoirs

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Abstract: Due to the nanometer scale pore size and extremely low permeability of a shale matrix, traditional Darcy's law can not exactly describe the combined gas transport mechanisms of viscous flow and Knudsen diffusion. Three transport models modified by the Darcy equation with apparent permeability are used to describe the combined gas transport mechanisms in ultra-tight porous media, the result shows that Knudsen diffusion has a great impact on the gas transport and Darcy's law cannot be used in a shale matrix with a pore diameter less than 1 μm. A single porosity model and a double porosity model with consideration of the combined gas transport mechanisms are developed to evaluate the influence of gas transport mechanisms and fracture parameters respectively on shale gas production. The numerical results show that the gas production predicted by Darcy's law is lower than that predicted with consideration of Knudsen diffusion and the tighter the shale matrix, the greater difference of the gas production estimates. In addition, the numerical simulation results indicate that shale fractures have a great impact on shale gas production. Shale gas cannot be produced economically without fractures.

Key words: Shale gas, gas transport mechanisms, viscous flow, Knudsen diffusion, fracture

1 Introduction

With a rapid decline in conventional petroleum reserves, unconventional resources are playing an increasingly important role in the volatile energy industry over recent years in North America and are gradually becoming a key component in the world's energy supply. Shale gas with huge reserves and extensive distribution represents a significant portion of unconventional natural gas resources and is becoming more important to the global energy supply in years to come (EIA, 2011).

The gas in shale gas reservoirs includes free gas in both fracture and matrix pores and adsorbed gas on the surface of matrix pores (Arogundade and Sohrabi, 2012; Hill and Nelson, 2000; Vermylen, 2011). The main pore size of shale matrix is in the range of 1-200 nm (Javadpour et al, 2007; Loucks et al, 2009; Zou et al, 2012). The widely used Darcy's law cannot be used in shale gas reservoirs because the gas transport in the shale matrix is not conventional viscous flow due to the existence of nanopores (Beskok and Karniadakis, 1999; Civan, 2010; Civan et al, 2011; Javadpour, 2009; Ziarani and Aguilera, 2012). Gas transport in nanopores is a combination of several flow mechanisms including viscous flow, Knudsen diffusion and molecular diffusion, which cannot be described by the Darcy equation (Bird et al, 2002). Moreover, the adsorption-desorption mechanism also occurs in the pores with adsorbed gas on the surface.

Several transport models have been developed to quantify gas transport in tight porous media with nanometer-size pores (Beskok and Karniadakis, 1999; Civan, 2010; Civan et al, 2011; Ho and Webb, 2006; Javadpour, 2009; Ziarani and Aguilera, 2012). Beskok and Karniadakis (1999) modified the second-order slip approximation to model rarefied gas flow in microchannels, ducts, and pipes. Civan (2010) used the Beskok model (Beskok and Karniadakis, 1999) to describe gas transport in tight porous media. Javadpour (2009) presented a gas transport model in gas shales considering viscous flow and Knudsen diffusion. All these models can describe combined gas transport mechanism in tight porous media; however, no numerical simulations of shale gas reservoirs are presented to investigate the difference in the production predicted by these transport models.

In this paper, a single porosity finite element model was developed and compared with other gas transport models (Darcy equation, the dusty gas model (DGM), Civan model and Javadpour model) for gas production in shale gas reservoirs. Due to the ultra-low permeability, shale gas reservoirs for commercial production are all developed shales with natural fractures (Arogundade and Sohrabi, 2012), which are the main permeable channels with much higher permeability than the matrix. Based on the dual-porosity hypothesis, we treat the shale gas reservoir as a dual porosity system consisting of a matrix system and a fracture system. Gas productions of shale gas reservoirs with different

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