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Pressure response and production performance of volumetric fracturing horizontal well in shale gas reservoir based on boundary element method

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ABSTRACT

The stimulated reservoir volume (SRV) creates a complex fracture network around the horizontal well in shale reservoirs, which significantly increases the gas well production. This paper considers gas desorption and multi-scale flow effects, and proposes a composite model with a double porosity continuum medium in the fractured area and a single porosity medium in the unfractured region. By employing the Laplace transform, source function theory, Green formula and boundary element theory, a semi-analytical solution of transient pressure is obtained in the volumetric fracturing reservoir with an arbitrary fractured region. The transient pressure and production performance of a volumetric fracturing horizontal well in the real space are obtained by means of Stehfest numerical inversion. Certain influences of relevant parameters on the performance of volumetric fracturing horizontal well are discussed. These parameters include the shape and size of the fractured region, hydraulic fracture number and length, permeability correction coefficient, and gas desorption coefficient. We demonstrate that these parameters have differing effects on the performance of the well. The results provided in this paper will aid in understanding the transient performance of a volumetric fracturing horizontal well in shale gas reservoirs, and promote the development of unconventional reservoirs.

1. Introduction

In the United States, the production of shale gas has been rapidly increasing in recent years, with more than 4200×10^8 m^3 in 2015, and accounting for approximately 50% of total natural gas production, which has a profound impact on US energy pattern [1]. The increase in shale gas production is due to the continuous maturity of the horizontal well completion process and horizontal well stimulated reservoir volume (SRV) technology. An SRV with a long distance horizontal well generates a complex fracture network in the reservoir [2,3]. Permeability is extremely low in shale reservoirs, and a fracture network with high permeability forms a main connecting channel between the wellbore and formation, vastly increasing the permeability of the fractured region and gas production of the well [4]. In shale gas reservoirs, the gas consists of adsorption, free, and dissolved gases, while there exist free molecular, diffusion, slippage, and Darcy flows when the gas flows. A massive volumetric fracturing horizontal well is used during exploitation, which results in the pressure response complexity and production performance of the horizontal well.

In shale reservoirs, gas is mainly presented in free and adsorbed gases, while a small amount of gas is dissolved in organic matter. Certain research studies have indicated that the adsorbed gas amount accounts for 20% to 85% [5,6]. In order to analyze the effects of adsorbed gas on well production performance, the Langmuir isothermal adsorption law is used to describe gas desorption. The shale reservoir's pore structure is complex and diverse, and includes nanopores and micro-pores [7,8]. As a result of the multi-scale flow effect, the gas flow contains free molecular, diffusion, slippage, and Darcy flows [9–11]. Heller et al. [12] verified the existence of diffusion and slippage flows in nanopores, and analyzed the contribution of these to flow capacity. In order to characterize the influence of multi-scale flow effect on flow capacity, certain scholars have proposed apparent permeability [13,14]. Ziarani [15] compared Klinkenberg's apparent permeability model with that of Knudsen, and found that Knudsen's model is a high-order correction model of Klinkenberg's; when the Knudsen number is larger, Knudsen's model is more suitable for tight gas reservoirs. Li et al. [16] introduced Knudsen's model into transient pressure calculation, and discussed the effect of adsorbed gas volume and apparent permeability on pressure response. The Langmuir's isothermal adsorption law and apparent permeability correction model can be used in the dynamic prediction of shale gas reservoirs.

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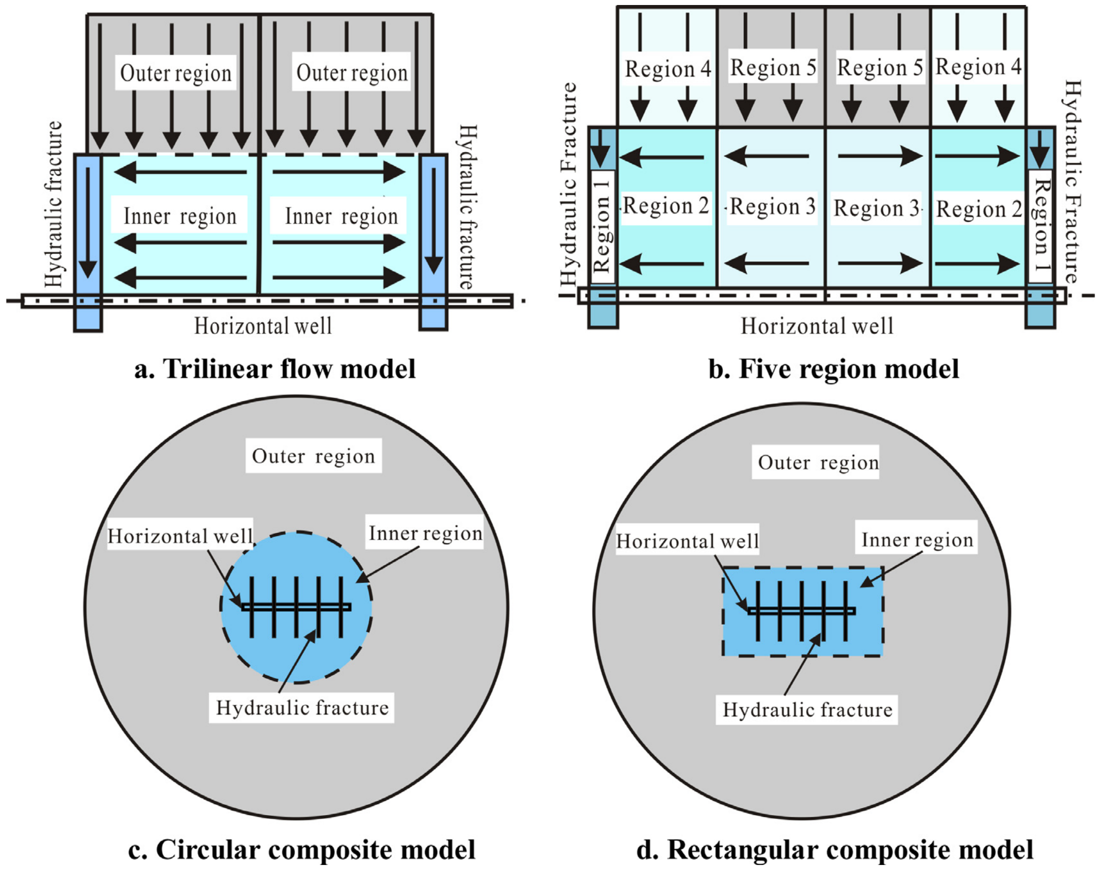

Fig. 1. Presentation models of hydraulic fractured horizontal well.

Furthermore, composite models have been employed to describe SRV in shale gas reservoirs. Lee and Brockenbrough [17] first proposed the trilinear flow model. In this model (Fig. 1a), the first linear flow is from the fracture to the wellbore, the second is from the inner region to the fracture, and lastly, a linear flow exists from the outer to inner region. Brown et al. [18] and Brohi et al. [19] applied the trilinear flow model to predict fractured horizontal well performance in shale gas reservoirs. Considering the differences in reservoir properties, Stalgorova and Mattar [20] extended the trilinear flow model to a five linear flow model (Fig. 1b), which can not only simulate the partial SRV but also take into account the fluid supplement beyond the fractures. These linear flow models simplify the gas flow into a linear flow; however, nonlinear flow exists in gas reservoirs. The circular composite model (Fig. 1c), and rectangular composite model (Fig. 1d) are used in volumetric fracturing shale gas reservoirs. The circular composite model is used for studying pressure response and production performance of a volumetric fracturing horizontal well in a tight gas reservoir; however, gas desorption and non-Darcy flow are not considered in this model [21]. Guo et al. [22] applied this model for the dynamic prediction of a shale gas reservoir, which takes into account desorption and non-Darcy flow. As the fractured region of the horizontal well may be elongated, a rectangular composite model has been introduced. Fan et al. [23] used this model to analyze pressure behavior and production performance of a volumetric fracturing horizontal well, without considering diffusion flow mechanism. Zhang et al. [24] studied the multi-scale flow effect and applied this model to shale gas reservoirs. According to the results of microseismic detection during the fracturing process, the fractured region is the concentrated zone of the colorful point, and is irregular (Fig. 2); therefore, a shale gas reservoir with a volumetric fracturing horizontal well is simplified as the above models, which fails to reflect the effects of fractured region shape.

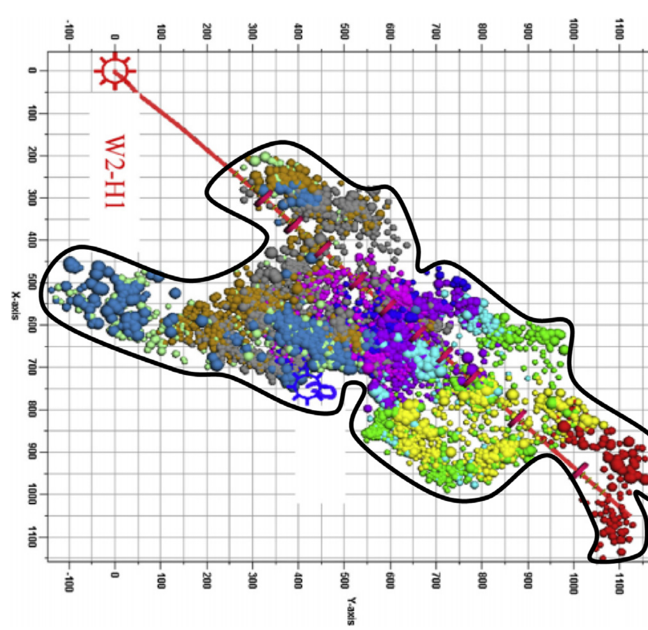

Fig. 2. Micro-seismogram of fracturing horizontal well [25].

This paper presents a composite model to describe the flow of a volumetric fracturing horizontal well in shale gas reservoirs. It contains a double porosity continuum model in an arbitrary shape of the fractured area and a single porosity model in the unfractured region. The model takes into account the multiple flow mechanisms in a shale gas reservoir. Source function theory and the boundary element method are applied