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A composite model of hydraulic fractured horizontal well with stimulated reservoir volume in tight oil & gas reservoir

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ABSTRACT

Due to the low porosity and permeability, multiple hydraulic fracturing is applied in tight oil & gas reservoir. A composite model of multiple fractured horizontal well is built with considering the stimulated reservoir volume (SRV), where the reservoir is divided into three main areas including fractures, stimulated reservoir volume and unstimulated reservoir. The dimension of fracture is reduced based on the discrete fracture model (DFM) to improve the computational efficiency, the stimulated reservoir volume follows the dual permeability model, and the unstimulated reservoir obeys to the single porosity model. The composite model is solved using the finite element method and verified by the classic analytical solution in dual porosity reservoir. The result shows that there are five main flow regimes for the multi-fractured horizontal well (MFHW) in the composite model including linear flow around the hydraulic fractures, pseudo-steady flow of transition area, inter-porosity flow period, radial flow of unstimulated reservoir and the outer boundary pseudo-steady flow. The bigger the size of SRV is, the later the pseudo-steady flow of transition area arrived, so according to the arrival time of pressure wave to the SRV outer boundary, namely the pseudo-steady flow of transition area appeared, the size of SRV can be determined; and the smaller main hydraulic fracture permeability is, the later the time of pseudo-steady flow of transition area arrived.

1. Introduction

With the application of technologies such as horizontal well drilling, synchronous fracturing and micro-seismic fracture diagnosis, the exploitation of tight oil & gas resources grows rapidly. Mayerhofer et al. (2006) firstly proposed the conception 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).

The performance of multiple fractured horizontal well has been studied a lot over the past decades. The source/Green's function method was introduced into petroleum engineering (Gringarten et al., 1973), which considerably expanded our ability to solve the transient flow problems. Then the solutions of fractured horizontal well were obtained by many authors (Guo and Evans, 1993; Chen and Raghavan,1997). After that, a new approach which combined Laplace transformation with source function solutions was built (Ozkan, 1991a, 1991b), where the influence of wellbore storage, skin factor and dual porosity media can be incorporated, and the relevant pressure solution about fractured horizontal well was obtained in Laplace space (Zerzar and Bettam, 2003; Al-Kobaisi and Ozkan, 2004). Zhao et al. (2013) used source function to analyze the transient pressure response of the multiple fractured horizontal well in shale gas reservoir. No matter in conventional or unconventional reservoir, most of the models did not consider the SRV, which is more consistent with the real geological situation.

Ozkan et al. (2009, 2011) used the tri-linear flow model to simulate the pressure transient and production behavior of fractured horizontal wells in unconventional reservoirs, including the fracture network around the hydraulic fractures. After that many works (Brown et al., 2011; Stalgorova and Mattar, 2012a, 2012b) have been done which are improved the tri-linear flow model to MFHW surrounded by a simulated region. The tri-linear model is

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simple and convenient to compute and apply, but the model assumes that all fractures have the same length and conductivity and uniformly along the horizontal well, which cannot take different geological conditions into consideration.

In order to study the flow characteristics of the MFHW more accurately, the paper built a composite model with SRV in tight oil & gas reservoir which was divided into three main areas. In addition, fractured horizontal well flow regimes with considering SRV and influence factors are analyzed, which is different from conventional MFHW without SRV model, so it can provide effective technical support for the exploitation and production prediction of unconventional oil & gas resources.

2. Building the MFHW model considering the SRV

2.1. Physical model

Due to the low porosity and permeability in tight oil & gas reservoir, natural productivity of single well is less than the low limit for effective economic exploitation, so horizontal well drilling is required, which can increase the contact area with wellbore in oil & gas layer, then combined with multiple hydraulic fracturing which can create multiple hydraulic fractures as well as connecting and opening natural fracture effectively. Based on multiple hydraulic fracturing process and SRV formation in tight reservoir, a composite reservoir of multi-stage fractured horizontal well is built with considering SRV as shown in Fig. 1. Assume a horizontal well is located in a box closed cubic drainage area. The reservoir size of *x*-, *y*-, *z*-direction is equal to *Xe*, *Ye*, *h* and the length of horizontal well is equal to *L*. The horizontal well is stimulated by hydraulic fracturing. Main fracture number is equal to N_f.

The composite model of MFHW divides reservoir into three main flow areas: (1) hydraulic fractures distributed along the horizontal well with different length and conductivity, but the fractures propagation is limited and obeys Darcy's law. (2) Stimulated reservoir volume SRV: natural fractures are opened and connected. SRV is made up of matrix and micro-fractures and can be described with dual porosity model. The permeability of matrix system is very low compared with micro-fracture system. So the inter-porosity flow between them is pseudo-steady and it can be determined only by pressure difference between matrix and micro-fracture system. (3) Unstimulated reservoir: the matrix characteristics are the same in unstimulated and stimulated reservoir. It has the same permeability and porosity.

Based on above assumption, horizontal well is barefoot or perforated completion. The bottom hole pressure is analyzed while it produces with constant rate. Meanwhile, transient productivity is calculated with constant bottom hole flow pressure, suppose isothermal flow in the reservoir and thin oil layer, where gravity effect can be ignored.

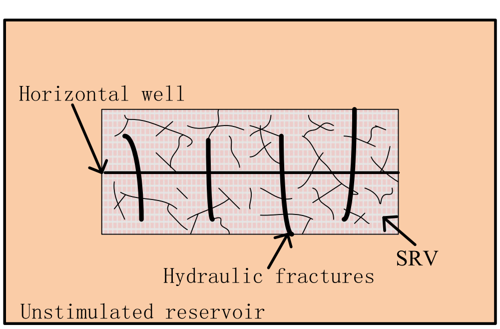

Fig. 1. Physical model diagram of MFHW in composite reservoir.

2.2. Mathematical model

(1) hydraulic fractures

Assuming fluid flow in the hydraulic fractures obeys Darcy's law, the pressure is equal on the boundary of fractures and matrix. The mathematical model for hydraulic fractures is given by

$$\begin{cases} \phi_p C_p \dfrac{\partial p_p}{\partial t} - \nabla \cdot \left(\dfrac{k_p}{\mu} \nabla p_p \right) = q_p \delta(M - M') \\ p_p(x, y, z; t = 0) = p_i \\ p_p(x, y, z; t) = p_s(x, y, z; t) \quad (x, y, z) \in \partial \Omega_p \end{cases} \tag{1}$$

Where p_p is pressure of hydraulic fractures, Pa; p_s is pressure of micro-fracture, Pa; p_i is initial pressure, Pa; ϕ_p is porosity of hydraulic fracture; k_p is permeability of hydraulic fracture, m^2; C_p is total compressibility of hydraulic fracture, Pa^{-1}; μ is viscosity of fluids, Pa·s ; q_p is volumetric flow rate per unit volume of source and sink in the hydraulic fracture, 1/s ; $\partial\Omega_p$ is boundary of hydraulic fracture; *M* is a any formation point and *M*′ is the insection point of hydraulic fractures with wellbore, then the $\delta(M-M')$ is delta function, the value is one at $M = M'$ or zero in other cases.

(2) Stimulated reservoir volume SRV

The SRV follows dual porosity model. Fluid flow in micro-fracture and matrix system obeys Darcy's law and inter-porosity flow between them is pseudo-steady. So flow equation of micro-fracture system is given by

$$\phi_s C_s \frac{\partial p_s}{\partial t} - \nabla \cdot \left(\frac{k_s}{\mu} \nabla p_s \right) - \frac{\alpha k_m}{\mu} (p_m - p_s) = q_s \delta(M - M') \tag{2}$$

Flow equation of matrix system is given by

$$\phi_m C_m \frac{\partial p_m}{\partial t} - \nabla \cdot \left(\frac{k_m}{\mu} \nabla p_m \right) + \frac{\alpha k_m}{\mu} (p_m - p_s) = 0 \tag{3}$$

Initial condition is

$$p_m(x, y, z; t = 0) = p_s(x, y, z; t = 0) = p_i \tag{4}$$

The inner boundary is that the pressure of hydraulic fractures is the same to the micro-fracture on the boundary, namely

$$p_s(x, y, z; t) = p_p(x, y, z; t) \quad (x, y, z) \in \partial\Omega_{in} \cap \partial\Omega_p \tag{5}$$

The outer boundary is that matrix system pressure is the same as unstimulated area pressurep_m. Where ϕ_m , ϕ_s are the porosity of matrix and micro-fracture system respectively; k_m , k_s are the permeability of matrix and micro-fracture system respectively, m^2; q_s is volumetric flow rate per unit volume of source and sink in micro-fracture system, 1/s ; α is the inter-porosity flow coefficient of matrix system to micro-fracture system, whose value is determined by surface area, pore structure of rock.

(3) Unstimulated reservoir area

The matrix in unstimulated area is the same as matrix system of dual porosity media in SRV. The inner boundary pressure of matrix system is equal to the matrix system pressure of dual porosity media. The outer boundary is closed. The initial pressure is constant, p_i.So the mathematical model for unstimulated area matrix system is given by