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Long cracks fractured vertical well numerical simulation and application for tight oil reservoir

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Abstract

Tight oil has currently become a hot issue in worldwide non-conventional oil exploration. Based on the core displacement experiments, the existence of low velocity non-Darcy flow was proven. So the three-dimensional three-phase Long cracks fractured vertical well model was established with considering the non-Darcy flow. A new numerical simulation software for long cracks fractured vertical well was developed. Results are compared to the simulation results of Darcy flow with the commercial simulator Eclipse. Using this new software, the comprehensive comparison and analysis of the simulation results of Darcy flow and non-Darcy flow were provided including oil production rate, water cut, reservoir pressure. The numerical simulator based on low velocity non-Darcy flow can describe tight sandstone reservoir development dynamic characteristics more exactly.

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*Keywords:*non-Darcy flow; tight sandstone reservoir; numerical simulation; long cracks fractured vertical well; three-dimensional three-phase model

1. Introduction

Tight oil has currently become a hot issue in worldwide non-conventional oil exploration. For low-permeability tight sandstone reservoir, fluid flow in porous media no longer obeys Darcy's law and instead conforms to the one of low-velocity non-Darcy flow or nonlinear flow[1-2]. In this letter, the nonlinear flow reservoir mathematical model is established based on the characteristics of the fluid flow in low permeability porous media, and the well-grid equation is deduced[3].

As an important technique long cracks fractured vertical well has been widely used in recent years in tight

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sandstone reservoir. However, fluid flow does not follow Darcy's law in tight sandstone reservoirs. The traditional commercial software always consider Darcy's flow, so, the development of suitable new software for tight sandstone reservoir is necessary. What's more, water flooding is a mature secondary recovery method for conventional reservoirs, it has been applied in tight sandstone reservoirs in a large commercial scale. Therefore, long cracks fractured vertical well numerical simulation technology is necessary to be established which can guide the tight sandstone reservoir development.

This letter was organized as following: Firstly, with considering the non-Darcy flow, the three-dimensional three-phase long cracks fractured vertical well numerical simulator was developed. Secondly, the comprehensive comparison and analysis of the simulation results of Darcy flow with Eclipse were provided. Finally, the development characteristics of long cracks fractured vertical well was given by comparing the strong non-Darcy model, non-Darcy model and Darcy model.

2. Numerical simulation model for long cracks fractured vertical well model

2.1. Assumption

(1) Capillary force and gravity effect are considered; (2) the flow is isothermal; (3) there are at most three components in reservoir; (4) the gas can achieve phase equilibrium instantaneously; (5) the oil and water phase obey non-Darcy's model;

2.2. Mathematical model

In tight reservoir the throat in porous media is nano/micro scale, the permeability is changing with the pressure gradient. Some scholars has put forward some classical models to describe this phenomenon. In order to describe the non-Darcy flow curve of tight sandstone reservoir, the low velocity non-Darcy flow model by Jiang et al. was used[4].

1) Motion equation

In matrix, the permeability is low, so the fluids obey non-Darcy model, and the motion equations are followed:

$$v_o = -\frac{KK_{ro}}{\mu_o}(1-\frac{\xi_{1o}}{\nabla p_o - \xi_{2o}})\nabla p_o ; v_w = -\frac{KK_{rw}}{\mu_w}(1-\frac{\xi_{1w}}{\nabla p_w - \xi_{2w}})\nabla p_w ; V_g = -\frac{KK_{rg}}{\mu_g}\nabla p_g \tag{1}$$

2) The continuity equation

Oil, Water, Gascomponent:

$$\begin{aligned} &-\nabla\cdot\left(\rho_o v_o\right)+q_o=\frac{\partial\left(\phi\rho_o S_o\right)}{\partial t};-\nabla\cdot\left(\rho_w v_w\right)+q_w=\frac{\partial\left(\phi\rho_w S_w\right)}{\partial t} \\ &-\nabla\cdot\left(\rho_{od}v_o+\rho_{wd}v_w+\rho_g v_g\right)+q_g=\frac{\partial}{\partial t}\left[\phi\left(\rho_{od}S_o+\rho_{wd}S_w+\rho_g S_g\right)\right] \end{aligned} \tag{2}$$

3) Numerical simulation model

By put the motion equations into continuity equation, the complete numerical simulation model was derived which is composed of flow equation, boundary conditions and initial condition.

Oil component：

$$\nabla\cdot\left(\frac{KK_{ro}}{B_o\mu_o}(1-\frac{\xi_{1o}}{\nabla P_o-\xi_{2o}})[\nabla\left(p_o-\rho_o gD\right)]\right)+q_{ov}=\frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right) \tag{3}$$

Water component：

$$\nabla\cdot\left(\frac{KK_{rw}}{B_w\mu_w}(1-\frac{\xi_{1w}}{\nabla p_w-\xi_{2w}})[\nabla\left(p_w-\rho_w gD\right)]\right)+q_{wv}=\frac{\partial}{\partial t}\left(\frac{\phi S_w}{B_w}\right) \tag{4}$$

Gas component：

$$\nabla\cdot\left[\frac{R_{so}KK_{ro}}{B_o\mu_o}(1-\frac{\xi_{1o}}{\nabla p_o-\xi_{2o}})\nabla\left(p_o-\rho_o gD\right)\right]+\nabla\cdot\left[\frac{R_{sw}KK_{rw}}{B_w\mu_w}(1-\frac{\xi_{1w}}{\nabla p_w-\xi_{2w}})\nabla\left(p_w-\rho_w gD\right)\right]$$
$$+\nabla\cdot\left[\frac{KK_{rg}}{B_g\mu_g}\nabla\left(p_g-\rho_g gD\right)\right]+q_{gv}=\frac{\partial}{\partial t}\left[\phi\left(\frac{S_g}{B_g}+\frac{R_{so}S_o}{B_o}+\frac{R_{sw}S_w}{B_w}\right)\right] \tag{5}$$

4) Auxiliary equation

Saturation equation: $S_o+S_w+S_g=1$ (6)

Capillary pressure equation: $p_{cow}=p_o-p_w \quad p_{cog}=p_g-p_o$ (7)

Initial condition: $p_w\big|_{i=0}=p_{wi}\left(x,y,z\right);S_w\big|_{i=0}=S_{wi}\left(x,y,z\right);S_o\big|_{i=0}=S_{oi}\left(x\ y\ z\right),$ (8)

Outer boundary：

Closed boundary $\frac{\partial\left(p_o-\rho_o gD\right)}{\partial n}\big|_{\Gamma}=0;\frac{\partial\left(p_w-\rho_w gD\right)}{\partial n}\big|_{\Gamma}=0;\frac{\partial\left(p_g-\rho_g gD\right)}{\partial n}\big|_{\Gamma}=0$ (9)

Constant pressure boundary $p_o\big|_{\Gamma}=const;p_w\big|_{\Gamma}=const;p_g\big|_{\Gamma}=const$ (10)

Inner boundary condition: In this study, Peaceman's well model was used[5].

Where ∇p is pressure gradient, Pa/m; K is permeability, m^2 ; Kr is relative permeability, dimensionless; ν is velocity, m/s; μ is fluid viscosity, Pa·s; S is saturation, fraction; B is volume coefficient, m^3/m^3 ; Pc is capillary pressure, Pa; q is mass production rate, m^3/s; qv is volume production rate, kg/s; t is time, s; x,y,z is Cartesian coordinate; ρ is density, kg/m^3; φ is porosity, %; P is pressure, Pa; Γ is boundary domain; o,w,g is oil, water, gas; Γ is boundary domain.

2.3. Solution

The fully implicit method is adopted to solve these discrete equations, in which the unknowns are solved simultaneously. The non-Darcy coefficients are also updated iteration but iteration. Then the non-Darcy flow numerical simulation program of three-dimension and three-phase in tight sandstone reservoir was compiled.

2.4. Illustrative examples and results

The commercial simulator Eclipse is very famous software in petroleum industry but can't consider the non-Darcy flow. In this model, fluid flow obeys Darcy flow by setting ξ1=0, ξ2=0. As shown in Fig1-2, the results from our model are in good agreement with Eclipse.

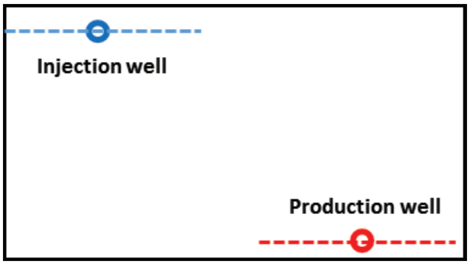

Fig. 1. validation model for numerical simulation

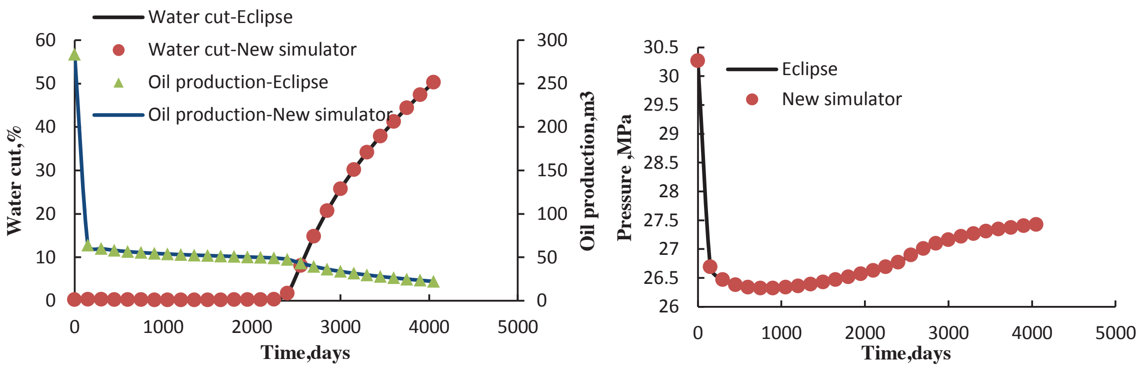

Fig. 2. (a) comparison curves of water cut and production rate; (b) comparison curves of pressure.

3. Development characteristics of long cracks fractured vertical well

To analyze the effect of non-Darcy flow, three examples were simulated: example one is Darcy's model by setting $\xi_1=0$, $\xi_2=0$;example two is non-Darcy flow model by setting $\xi_1=0.025$, $\xi_2=-0.025$;example three is also a non-Darcy flow model and the non-Darcy degree is much higher by setting $\xi_1=0.1$, $\xi_2=-0.1$.

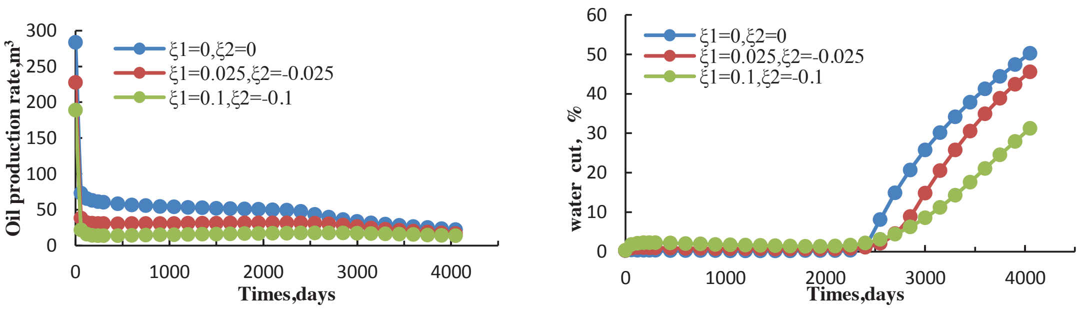

Fig. 3. (a) comparison curves of oil production rate; (b) comparison curves of water cut.

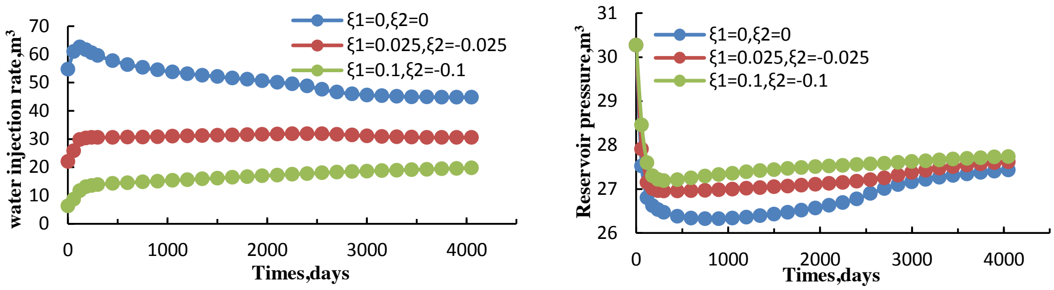

Fig. 4. (a) comparison curves of water injection rate; (b) comparison curves of reservoir pressure.

Fig. 3 give the oil production rate and water cut under different flow models. It can be seen that non-Darcy model has a lower oil production rate and water cut compared with the Darcy's model. If the non-Darcy degree is higher, the oil production rate is much lower and descends more rapidly, breakthrough time become more behind and the water cut is much lower. Fig. 4 give the water injection rate and reservoir pressure under different flow models. It can be seen that the water intake capability of injection well are higher than that of non-Darcy model, and the reservoir pressure is lower than that of non-Darcy model. As the non-Darcy degree becomes higher, the reservoir pressure become higher, the water intake capability and liquid production capability become lower. The non-Darcy degree becomes higher, the water intake capability and liquid production capability for tight sandstone reservoir become more difficult. Above all, fluid flow in reservoir consumes more driving energy and the water flooding efficiency becomes lower. Darcy flow model overstates the reservoir flow capability, the non-Darcy flow need to be considered in tight sandstone reservoir which can estimate the reservoir flow resistance reasonably.

4. Conclusion

The long cracks fractured vertical well simulator was developed for tight sandstone reservoir considering the non-Darcy flow. With considering the non-Darcy flow, the fluid flow in reservoir consumes more driving energy, the water flooding efficiency was reduced.

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