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Effects of the wellbore parameters of radial horizontal micro-holes on the gas reservoir production rate

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A B S T R A C T

Radial horizontal drilling technology can create several drainage micro-holes to improve the efficiency of fluid flowing from the reservoir into the wellbore, increase the single-well production rate and enhance the recovery of natural gas. This paper proposes a steady-state model to calculate the production rate of natural gas for radial horizontal micro-holes by coupling the reservoir inflow model and the wellbore flow model. The newly developed model calculates the friction pressure loss for gas flow in the radial horizontal wellbore. The influences of certain wellbore parameters on gas production rate have been analyzed, and a sensitivity study has been performed. The results show that the production rate increases as the wellbore length, the number of micro-holes, the included angle and wellbore diameter increase. However, the effects of the number of micro-holes, the included angle and the wellbore diameter are significant only within certain limits. Based on the degree to which the parameter positively affects the gas production rate, the wellbore parameters can be ranked as follows: wellbore length > the number of micro-holes > included angle > wellbore diameter > distance between the micro-hole and the lower boundary. The wellbore length and the number of micro-holes have the greatest influence on the production rate of multiple radial horizontal micro-holes. The models and results presented in this paper can provide the theoretical basis for the design of radial horizontal drilling in natural gas reservoirs.

1. Introduction

The radial horizontal drilling technology is designed to provide multiple lateral micro-holes from a main wellbore, traditionally utilizing high-pressure water jet to break the formation rock (Dickinson et al., 1989; Li et al., 2000). It has made it possible to expose the oil and gas formation as much as possible. It is proved to be effective to develop low permeability hydrocarbon in many countries (Toma et al., 1991; Raul and Juan, 2007; Stanislay et al., 2008; Abdel-Ghany et al., 2011).

Natural gas is currently the third largest global energy source and plays an important strategic role in the world's energy supply (Leather et al., 2013). In addition, it can help achieve two important energy goals – providing sustainable energy supplies and services and reducing adverse impacts on global climate and the environment (Economides and Wood, 2009). Radial horizontal drilling technology is potentially a cost-effective method that can stimulate coal-bed methane production (Palmer, 2010; Zhang et al., 2010). Six lateral radial horizontal micro-holes were jetted into Well Q2-3-313 in the Liaohe oil field in China to stimulate heavy oil production; the oil production rate increased from 0 to an average of 6500 m^3/day over three months (Gao, 2012).

The equipment and methods required for radial horizontal drilling have been studied by many scholars. However, no theoretical method provides guidelines for the design of radial horizontal micro-holes, although analytical and semi-analytical models have been developed to predict the production rate of radial horizontal micro-holes (Xi et al., 2004; Li, 2014). However, existing models can only be applied to a single radial horizontal micro-hole, even though several radial horizontal micro-holes are typically drilled from the main wellbore. Furthermore, the fluid flowing into a lateral can interfere with fluid flowing into other laterals and cause a decrease in the inflow rate, a phenomenon known as the multiple-well interference effect. However, this multiple-well interference effect and reservoir boundary conditions are seldom considered in existing models.

This study has developed a steady-state semi-analytical model is developed to predict the production rate of natural gas by coupling reservoir inflow with the wellbore flow. The multiple-well

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interference effect is incorporated into the reservoir inflow model according to the potential superposition principle. A program is made to predict the performance of several radial horizontal micro-holes at different depths in the reservoir.

2. Mathematic model

2.1. Model of gas flow from reservoir into wellbore

Assuming that the wellbore radius of the lateral is negligible relative to the wellbore length, the micro-hole can be modeled as a line source. The reservoir is assumed to be homogeneous and far away from the micro-holes. The flow potential around the reservoir is constant. The fluid is assumed to be gas, and the gas flow is in a steady state following Darcy's Law. The mother-well is completed with a casing, and micro-holes are open hole.

According to the mathematical model of fluid flow in a porous medium and the theory of potential, the governing equation for steady-state fluid flow in the reservoir (Faruk, 2011) is

$$\frac{\partial^2 \Phi}{\partial x^2}+\frac{\partial^2 \Phi}{\partial y^2}+\frac{\partial^2 \Phi}{\partial z^2}=0, \tag{1}$$

where, Φ is the flow potential.

Divide the radial horizontal micro-hole into segments (Fig. 1), and assume the number of segments is N_{ij}. The solution to Eq. (1) for an arbitrary spatial point M affected by a single segment with a constant gas flow rate is:

$$\Phi_M(i,j,k)=-\frac{q(i,j,k)B_g}{4\pi\cdot\Delta L(i,j,k)}\frac{1}{r_M(i,j,k)} \tag{2}$$

The subscript i is the position index of the main wellbore, j is the micro-hole index at position i, and k is the segment index of micro-hole j. The parameter $r_{M(i,j,k)}$ is the distance of point M from an arbitrary point on the segment, q is the gas flow rate of a segment under standard conditions, and ΔL is the segment length. B_g is the gas formation volume factor, which is expressed as:

$$B_g=\frac{p_{sc}TZ}{pT_{sc}Z_{sc}} \tag{3}$$

where, p_{sc}, T_{sc} and Z_{sc} are the gas pressure, temperature and Z-factor, respectively, under standard conditions. Similarly, p, T and Z are the gas pressure, temperature and Z-factor, respectively.

Considering the relationship between potential and pressure, the differential of potential due to gas flow in a small section with length $-$ dl of the segment is:

$$\frac{p}{\mu Z}\mathrm{d}p=-\frac{p_{sc}Tq(i,j,k)}{4\pi KT_{sc}Z_{sc}\Delta L(i,j,k)}\frac{1}{r_M(i,j,k)}\mathrm{d}l \tag{4}$$

Equation (4) integrated over the segment length is:

$$\int\frac{p}{\mu Z}\mathrm{d}p=\int_0^{\Delta L(i,j,k)}-\frac{p_{sc}Tq(i,j,k)}{4\pi KT_{sc}Z_{sc}\Delta L(i,j,k)}\frac{1}{r_M(i,j,k)}\mathrm{d}l$$
$$=-\frac{p_{sc}Tq(i,j,k)}{4\pi KT_{sc}Z_{sc}\Delta L(i,j,k)}\ln\frac{r_{1M}(i,j,k)+r_{2M}(i,j,k)+\Delta L(i,j,k)}{r_{1M}(i,j,k)+r_{2M}(i,j,k)-\Delta L(i,j,k)} \tag{5}$$

where, K is the reservoir permeability, which is equal to:

$$K=\sqrt{K_hK_v} \tag{6}$$

The expression of the gas pseudo pressure (Dake, 1978) is:

$$\Psi=2\int\frac{p}{\mu Z}\mathrm{d}p \tag{7}$$

Thus, Eq. (5) can be rewritten as:

$$\Psi_M(i,j,k)=-\frac{p_{sc}Tq(i,j,k)}{2\pi KT_{sc}Z_{sc}\Delta L(i,j,k)}\ln\frac{r_{1M}(i,j,k)+r_{2M}(i,j,k)+\Delta L(i,j,k)}{r_{1M}(i,j,k)+r_{2M}(i,j,k)-\Delta L(i,j,k)} \tag{8}$$

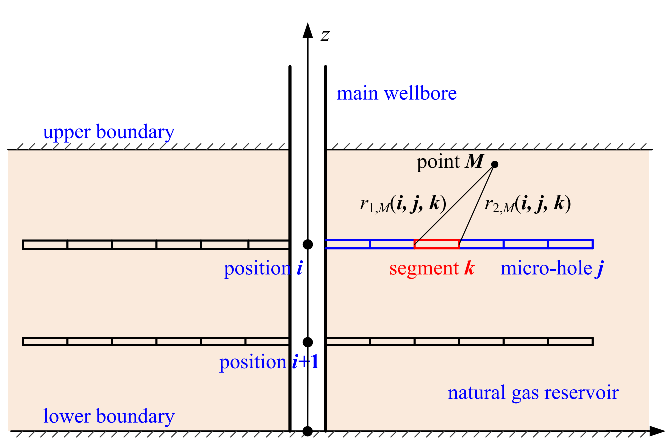

Fig. 1. Segmentation and numbering of radial horizontal micro-holes.

where, r_{1M} and r_{1M} represent the distance from point M to the end, which is close to the heel and toe of the micro-hole, respectively.

$$\begin{cases} r_{1M}(i,j,k)=\sqrt{[x_1(i,j,k)-x]^2+[y_1(i,j,k)-y]^2+[z_1(i,j,k)-z]^2} \\ r_{2M}(i,j,k)=\sqrt{[x_2(i,j,k)-x]^2+[y_2(i,j,k)-y]^2+[z_2(i,j,k)-z]^2} \end{cases} \tag{9}$$

We now define ξ:

$$\xi_M(z_1(i,j,k),z_2(i,j,k))=\ln\frac{r_{1M}(i,j,k)+r_{2M}(i,j,k)+\Delta L(i,j,k)}{r_{1M}(i,j,k)+r_{2M}(i,j,k)-\Delta L(i,j,k)} \tag{10}$$

Finally, Eq. (9) can then be simplified as:

$$\Psi_M(i,j,k)=-\frac{p_{sc}Tq(i,j,k)}{2\pi KT_{sc}Z_{sc}\Delta L(i,j,k)}\xi_M(z_1(i,j,k),z_2(i,j,k)) \tag{11}$$

The method of images is applied to study the influence of the top and bottom boundaries of the reservoir on the reservoir fluid flow. An infinite grid of image segments is implemented in order to maintain the flow condition at the top and bottom boundaries (Dake, 1978). The image segments can fall into two categories –