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Journal of Natural Gas Geoscience xx (2016) 1−10

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Original research paper

A new method in predicting productivity of multi-stage fractured horizontal well in tight gas reservoirs☆

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Received 3 August 2016; revised 28 September 2016
Available online ■ ■ ■

Abstract

The generally accomplished technique for horizontal wells in tight gas reservoirs is by multi-stage hydraulic fracturing, not to mention, the flow characteristics of a horizontal well with multiple transverse fractures are very intricate. Conventional methods, well as an evaluation unit, are difficult to accurately predict production capacity of each fracture and productivity differences between wells with a different number of fractures. Thus, a single fracture sets the minimum evaluation unit, matrix, fractures, and lateral wellbore model that are then combined integrally to approximate horizontal well with multiple transverse hydraulic fractures in tight gas reservoirs. This paper presents a new semi-analytical methodology for predicting the production capacity of a horizontal well with multiple transverse hydraulic fractures in tight gas reservoirs. Firstly, a mathematical flow model used as a medium, which is disturbed by finite conductivity vertical fractures and rectangular shaped boundaries, is established and explained by the Fourier integral transform. Then the idea of a single stage fracture analysis is incorporated to establish linear flow model within a single fracture with a variable rate. The Fredholm integral numerical solution is applicable for the fracture conductivity function. Finally, the pipe flow model along the lateral wellbore is adapted to couple multi-stages fracture mathematical models, and the equation group of predicting productivity of a multi-stage fractured horizontal well. The whole flow process from the matrix to bottom-hole and production interference between adjacent fractures is also established. Meanwhile, the corresponding iterative algorithm of the equations is given. In this case analysis, the productions of each well and fracture are calculated under the different bottom-hole flowing pressure, and this method also contributes to obtaining the distribution of pressure drop and production for every horizontal segment and its changes with effective fracture half-length and conductivity. Application of this technology will provide gas reservoir engineers a better tool to predict well and fracture productivity, besides optimizing transverse hydraulic fractures configuration and conductivity along the lateral wellbore.

Keywords: Tight gas; Multi-stage hydraulically fractured horizontal well; Single fracture; Production interference between adjacent fractures; Productivity prediction

1. Introduction

There are many transverse fractures with different forms around a horizontal well after being fractured multi-stage in tight gas reservoirs, this greatly increases the contact area a between gas well and the formation. Simultaneously, the flow conditions around the bottom-hole are improved. The states of gas flow include Darcy flow in the formation pores, variable Darcy flow in the hydraulic fractures, and variable pipe flow in

☆ This is English translational work of an article originally published in *Natural Gas Geoscience* (in Chinese).The original article can be found at: 10.11764/j.issn.1672-1926.2016.06.1101.

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Peer review under responsibility of Editorial Board of *Journal of Natural Gas Geoscience*.

http://dx.doi.org/10.1016/j.jnggs.2016.10.004

the horizontal wellbore. The interferences and the coupling happen between the three flow patterns by means of the boundary conditions.

In terms of research on finite conductivity fractures, parts [1] unraveled the flow relationship between the elliptic fractures and matrix by conformal transformation; this presented the function relationship between finite conductivity and effective wellbore diameter. Cinco-Ley [2] evaluated the flow capacity of fractures with finite conductivity by the numerical discrete method. Liao [3] researched variable flow within fractures through transforming elliptic coordinate. On these bases, the analysis on unstable flow of fractured horizontal well within closed formation, Zerzar [4] obtained the characteristics of a linear (double) flow in the early stages, and a quasi-steady flow in the late stages done by the gradual approximation method; the parameters of the fractured horizontal well were then analyzed. Brown [5] used three linear flow models to reflect the flow law within the hydraulic fracture, the inner reservoir between hydraulic fractures, and the outer reservoir away from the tips of the fracture system. Regarding the productivity evaluation of fractured horizontal wells, based on the Joshi [6,7] productivity formula, Raghavan [8] introduced a method of predicting productivity of a multi-stage fractured horizontal well, which substitutes the equivalent wellbore radius (radial flow) for hydraulic fractures to simulate fluid flow. Wang [9] corrected the equivalent wellbore diameter of the horizontal wells with vertical rectangular fractures through introducing the influence function of finite conductivity fractures. Meanwhile, in combination with pressure superposition principle, the influence factors of fractured horizontal well productivity were evaluated. Wang [10] established the mathematical model flow of a multi-stage fractured horizontal well; the characteristics include the rectangular closed boundary by means of the two variables considering gas slippage, the pseudo-pressure, and the pseudo-time. Based on the wellbore with infinite conductivity, the change on horizontal well productivity is analyzed with the various fracture length, fracture conductivity, the number of fractures, fractured horizontal well length, and so on. Li [11] established the empirical plate to evaluate the open flow rate and cumulative production based on demonstrating the scale of the effective sand. Li [12] quickly evaluated the horizontal well productivity in low-permeability and tight gas reservoirs through combining ideal model with numerical simulation. In this paper, with the aid of previous research study results, the idea [13] of a single fracture is introduced to accurately evaluate the productivity of fractured horizontal wells in tight gas reservoirs. By a single fracture serving as a unit, the principle of mass conservation is applied to couple the elliptic flow in a typical reservoir, as well as variable flow within fractures and variable pipe flow in the horizontal wellbore. Meanwhile, considering the interference between the adjacent fractures, the theoretical formula, and the corresponding algorithm are established for predicting productivity of fractured horizontal wells; the practical examples are analyzed for model verification. Thus, a new method for predicting productivity of multi-stage fractured horizontal wells in a tight gas reservoir is formed.

2. Mathematical model

2.1. Flow model in formation with finite conductivity fracture

There are complex flow types in the reservoir with fractures. The gas in pores flow linearly into fractures across the surface, the streamline form within limit scope around fractures and is similar to an elliptic flow, and pseudo-radial flow is usually expressed out of the elliptic flow (Fig. 1).

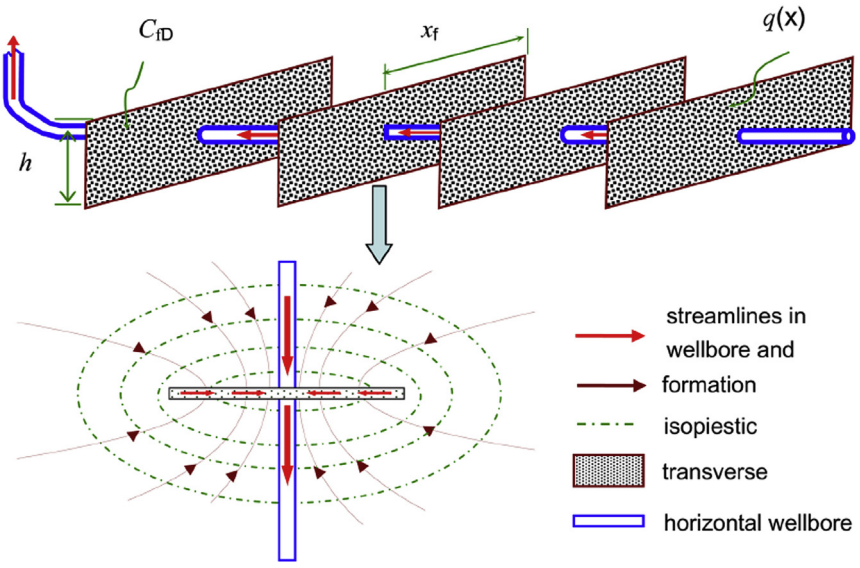

Fig. 1. Multi-stage fractured horizontal well and single fracture flow.

Please cite this article in press as: Y. Wei, et al., A new method in predicting productivity of multi-stage fractured horizontal well in tight gas reservoirs, Journal of Natural Gas Geoscience (2016), http://dx.doi.org/10.1016/j.jnggs.2016.10.004