CSCanada
Advances in Petroleum Exploration and Development
Vol. 8, No. 2, 2014, pp. 53-57
DOI:10.3968/5799

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Non-Linearity Seepage Productivity Model and Influential Factors' Analysis in Tight Sandstone Gas Reservoir

WANG Fengjiao[a]; LIU Yikun[a],*; LIANG Shuang[a]; CHEN Ruya[a]

[a] Northeast Petroleum University, Daqing, China.
* Corresponding author.

Supported by Major National Science and Technology Project "Large Oilfield and Coal-bed Gas Development", "The Development Effect Evaluation of Water Flooding and Studies on Optimization Methods of Measures" (2011ZX05052-004); The Creative and Scientific Research Project of Northeast Petroleum University "Study on Non-linearity Seepage Theory in Tight Sandstone Gas Reservoir" (YJSCX2014-010NEPU).

Received 15 September 2014; accepted 26 November 2014
Published online 29 December 2014

Abstract

The tight sandstone gas is the most precious unconventional natural gas resource which has massive reserves all over the world. However, poor formation physical properties, extremely lower permeability, and complex pore-throat structure make it difficult to effective displacement in the tight gas formation. As a result, fracturing of horizontal wells is an effective technique for the tight gas. Based on the natural gas non-linearity unsteady seepage theory, the pseudo-pressure pattern and the overlay principle, this paper sets up the fractured horizontal well productivity model in the tight sandstone gas reservoir, which takes fracture interferences into consideration. Combined with the productivity model above, the relation curves between cumulative gas production and different factors have been drawn, and the sensitivity analysis of productivity influential factors has been carried on as well. Research shows that: the best length of horizontal well is 900 m and the corresponding optimal number of fractures is 6, while the optimal half-length of the fracture is 80 m. The length of horizontal well is the most sensitive influential factor to the productivity, while other factors are half-length of the fracture and the fracture conductivity in turn. Seeing from the sensitivity analysis curve, the fractured horizontal well productivity is not sensitive to fracture conductivity in tight gas formation. The study has an important guiding significance to productivity prediction and parameters optimization of fractured horizontal wells in the tight sandstone gas reservoir.

Key words: Tight gas; Non-linearity seepage; Productivity prediction; Fractured horizontal well

Wang, F. J., Liu, Y. K., Liang, S., & Chen, R. Y. (2014). Non-linearity seepage productivity model and influential factors' analysis in tight sandstone gas reservoir. *Advances in Petroleum Exploration and Development*, *8*(2), 53-57. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/5799
DOI: http://dx.doi.org/10.3968/5799

INTRODUCTION

The tight sandstone gas is the most important development target in global unconventional gas area and it is the most likely one in exploitation of China as well. In the development process of tight sandstone gas reservoir, owing to its lower permeability, higher filtrational resistance and worse connectedness and so on, horizontal wells only development can't achieve the desired effect[1-3]. In order to improve the single well productivity and the recovery ratio entirely, fractured horizontal wells are widely used to increase the gas drainage area and improve fluid connectivity degree between reservoir and borehole, which can increase the horizontal wells productivity[4,5]. However, under different reservoir geological conditions, parameters related to fractures will be lead to different effects to horizontal wells' productivity[6-8]. Based on the basic unstable seepage flow differential equation of natural gas, the pseudo-pressure pattern and the overlay principle of natural gas non-linearity percolation, considering the tight gas seepage characteristics as well, this paper sets up the productivity prediction model of tight sandstone gas reservoir and analyses the parameters related to fractures such as length of horizontal well, half-length of the fracture, number of fractures, fracture conductivity and so on. The study has an important guiding significance for the actual production and fracturing design in the tight sandstone gas reservoir.

1. SET UP THE PRODUCTIVITY PREDICTION MODEL

Before setting up the productivity model, the following assumptions are made:

a. The upper surface and the lower surface of the reservoir are both closed and it is an infinite and homogeneous formation;

b. It is the open-hole completion in the horizontal well bore hole, so that the productivity depends on the open-hole section and fractures production after hydraulic fracturing completely;

c. The single phase fluid in the formations and fractures are both isothermal non-Darcy compressible flow;

d. Fractures penetrate the pay formations completely and they are all equally spaced, parallel, and perpendiculars to horizontal well's bore hole;

e. The fluid flows along crack's wall to the fracture evenly and then flows into horizontal well's bore hole through the fracture.

The tight gas pseudo-pressure function is:

$$m^* = 2\int_{p_a}^{p} \frac{p}{\mu_g(p)Z(p)}\mathrm{d}p \tag{1}$$

Where, p denotes the formation pressure, Pa; p_a denotes the pressure of any point, Pa; μ_g denotes the fluid's viscosity, Pa·s; Z denotes gas compressibility factor, non-dimension.

The solution of tight sandstone gas at the point of (x_0, y_0) in the unsteady seepage state is:

$$m_i^* - m^* = \frac{q_m}{2\pi Kh}\frac{p_{sc}T}{Z_{sc}T_{sc}\rho_{gsc}}\left[-Ei\left(\frac{-(x-x_0)^2+(y-y_0)^2}{4\eta t}\right)\right] \tag{2}$$

Where, q_m denotes gas mass flow, m^3/s; p_{sc} denotes standard pressure, Pa; T denotes the temperature in the formation, K; η the formation diffusivity coefficient, m^2·Pa/ (Pa·s); K denotes the formation permeability, m^2; t denotes the production time, s; Z_{sc} denotes the compressibility factor under standard conditions, non-dimension; T_{sc} denotes the temperature in the formation under standard conditions, K; ρ_{gsc} denotes natural gas density under standard conditions, kg/m^3.

In order to expedient express, we substitute the pressure for the pseudo-pressure and transform mass flow to volume flow rate:

$$p_i^2 - p^2 = \frac{q_{sc}\overline{\mu}}{2\pi Kh}\frac{p_{sc}\overline{Z}T}{Z_{sc}T_{sc}}\left[-Ei\left(\frac{-(x-x_0)^2+(y-y_0)^2}{4\eta t}\right)\right] \tag{3}$$

Divided the single half-fracture into n equal parts, each part can be regarded as a point convergence. Under the plane rectangular coordinate system, there is a point convergence whose delivery is q constantly in the infinite and homogeneous formation constant, and then the pressure drawdown equation at the point of (x_0, y_0) is as follows:

$$p_i^2 - p^2(x,y,t) = \frac{q_f\mu_g p_{sc}ZT}{4\pi KhT_{sc}}\left[-Ei\left[-\frac{(x-x_0)^2+(y-y_0)^2}{4\eta t}\right]\right] \tag{4}$$

Where, p_i denotes the original reservoir pressure, Pa; $p(x,y,t)$ denotes the formation pressure at each point (x, y) in the formation at the t moment, Pa; q_f denotes the production of the point source, m^3/s;

Assuming that there are N fractures in horizontal bole hole, the half-equal part j of the crack i will produce differential pressure to the fracture peak which is coincided with the following equation:

$$A = p_{eij}^2 - p_{wfij}^2 = \frac{q_{fij}\mu_g p_{sc}ZT}{4\pi KhT_{sc}}\times\left(-E_i\left(-\frac{(-x_{fij}+x_{fij})^2+(y_{fij}-y_{fij})^2}{4\eta t}\right)\right)+ \frac{q_{fij}\mu_g p_{sc}ZT}{4\pi KhT_{sc}}\times\left(-E_i\left(-\frac{(x_{fij}-x_{fij})^2+(y_{fij}-y_{fij})^2}{4\eta t}\right)\right) \tag{5}$$

In the same way, the other single half-equal part j of the crack i will satisfy the following relation:

$$B = p_{eij}^2 - p_{wfij}^2 = \frac{q_{fij}\mu_g p_{sc}ZT}{4\pi KhT_{sc}}\times\left(-E_i\left(-\frac{(x_{fij}+x_{fij})^2+(y_{fij}-y_{fij})^2}{4\eta t}\right)\right)+ \frac{q_{fij}\mu_g p_{sc}ZT}{4\pi KhT_{sc}}\times\left(-E_i\left(-\frac{(x_{fij}-x_{fij})^2+(y_{fij}-y_{fij})^2}{4\eta t}\right)\right) \tag{6}$$

Where, q_{fij} denotes the production of the part j in the crack i, m^3/s; x_{fij} denotes the X-coordinate of the part j in the crack i; y_{fij} denotes the Y-coordinate of the part j in the crack i.

The fluid accumulation from fracture peak to areas around the wellbore could be regarded as a radial fluid flow[9]. Through the method of analogy: The single fracture cross section has been likened to the plane of the radial fluid flow, as thus the flowing diameter will be equal to the fracture length and the formation thickness will be equal to the fracture width. In the same way, the fracture peak pressure and the well bore pressure will be equivalent as the supply boundary formation pressure and bottom hole flowing pressure as well. So the differential pressure in this process is coincided with the following equation:

$$C = p_{ei}^2 - p_{wfi}^2 = \frac{q_{fi}\mu_g p_{sc}ZT}{2\pi K_{fi}w_{fi}T_{sc}}\times\left(-E_i\left(-\frac{r_w^2}{4\eta t}\right)\right) \tag{7}$$

Where, K_{fij} denotes the permeability of the part j in the crack i, m^2; w_{fi} denotes the width of the crack i, m; r_w denotes the radius of the well bore, m.

When $-\frac{r^2}{4\eta t} < 0.01$, the Equation (7) can be represented as follows approximately:

$$C = \frac{q_{fi}\mu_g p_{sc} ZT}{2\pi K_{fi} w_{fi} T_{sc}} \times \ln \frac{2.25\eta t}{r_w^2} \tag{8}$$

$$p_e^2 - p_{wf}^2 = \sum_{i=1}^{N}\left[\sum_{j=1}^{n}(A+B)+C\right] \tag{9}$$

The total production output will be as follows:

$$Q = \sum_{i=1}^{N}\sum_{j=1}^{n} q_{fij} \tag{10}$$

$N \times n$ equations can be got, and there are $N \times n$ unknown numbers as well. For the linear equations, the relevant solutions will be got. In order to solve the equations easily, the whole resolution process is realized using Visual Basic language by programming.

2. ANALYSIS OF PRODUCTIVITY INFLUENTIAL FACTORS

In order to analyze the parameters related to fractured horizontal wells such as length of horizontal well, half-length of the fracture, number of fractures, fracture conductivity and so on, a typical tight gas well in the Ordos Basin is chosen to carry on the comparison and analysis with the fractured horizontal well productivity prediction model program above. The production cycle is 365 days. The basic parameters are as follows:

Table 1
Fluid Parameters of the Typical Tight Gas Well in the Ordos Basin

Parameters' types	Value	Parameters' types	Value
Reservoir thickness/m	15.0	natural gas viscosity/MPa·s	0.013
Reservoir permeability/mD	0.375	compressibility coefficient/MPa^{-1}	0.082
Average porosity/%	8.563	natural gas relative density	0.72
Original formation pressure/MPa	30	gas bearing temperature/℃	65
Volume factor	0.005	wellbore radius of horizontal well/m	0.12

2.1 Length of Horizontal Well

Figure 1 is the relation curve between cumulative gas production and the length of the horizontal well. The natural gas production increases with the increase of the horizontal well's length until it is more than 900 m. After this point, the cumulative gas production will not change apparently. Therefore, the reasonable length of the horizontal well is 900 m.

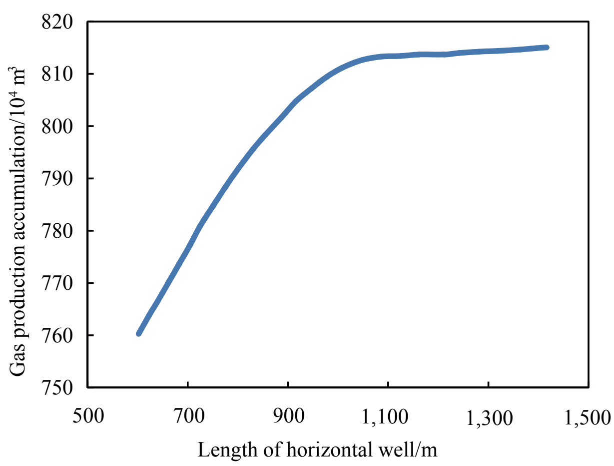

Figure 1
The Curve Between Cumulative Gas Production and Different Length of Horizontal Well

2.2 Number of Fractures

Figure 2 is the relation curve between cumulative gas production and number of fractures when the length of horizontal well is the optimum 900 m. With the increase of fractures' number, the natural gas production increases. However, the increasing amplitude is decreases inch by inch. The main reason for this is that the increase of fractures' number leads to the interspacing between fractures decreasing so that interactive disturbance gets more serious. Thus each fracture's production gets reduced, the amplification of fractured horizontal well's cumulative gas production will decrease as well. As a result, the optimum fractures' number is 6 while the length of horizontal well is 900 m。

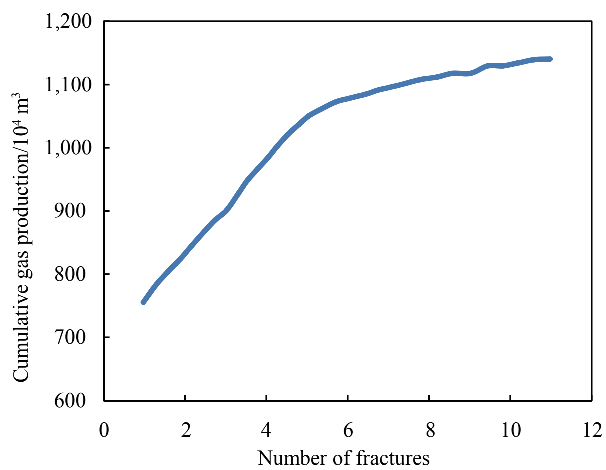

Figure 2
The Curve Between Cumulative Gas Production and Number of Fractures

2.3 Half-Length of the Fracture

Figure 3 is the relation curve between cumulative gas production and half-length of the fracture. The natural gas production increases with the increase of the horizontal well's half-length of the fracture, while the increasing amplitude is decreases gradually. The longer fracture length the better gas production, however, the flowing friction resistance gets bigger at the same time. As a result, the gas production will get undesirable influence. In this example, the optimum half-length of the fracture is 80 m drawing the conclusion from Figure 3.

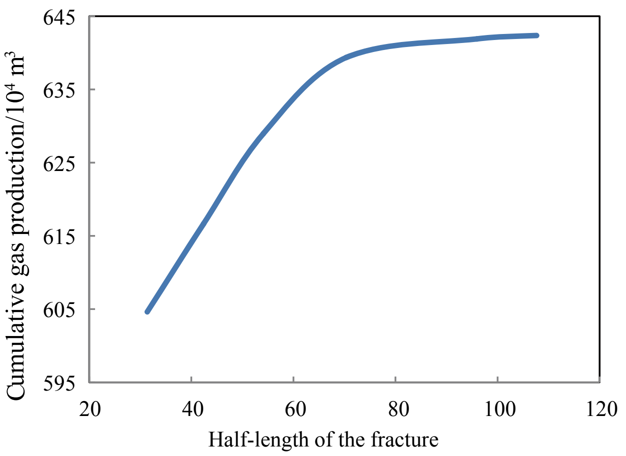

Figure 3
The Curve Between Cumulative Gas Production and Half-Length of the Fracture

2.4 The Fracture Conductivity

Figure 4 is the relation curve between cumulative gas production and the fracture conductivity. With the increase of the fracture conductivity, the cumulative gas production changes little. For the tight Sandstone gas reservoir, the effect of fracture conductivity can be neglected.

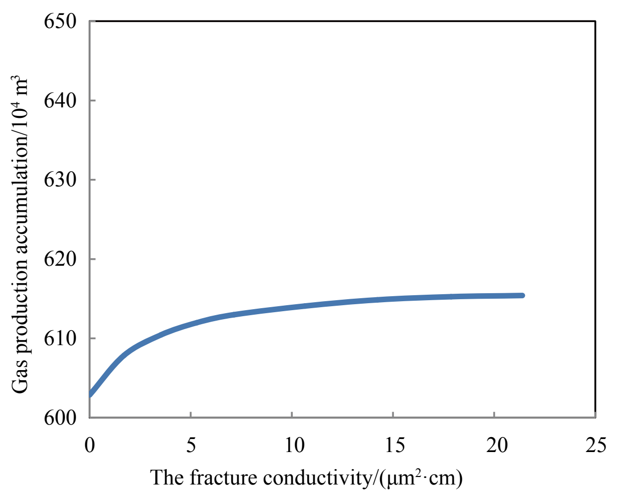

Figure 4
The Curve Between Cumulative Gas Production and the Fracture Conductivity

3. SENSITIVITY ANALYSIS OF INFLUENTIAL FACTORS

Based on the fractured horizontal well productivity prediction model above, the sensitivity analysis of productivity influential factors has been carried on, whose results are shown in Figure 5. It is the curve between the parameter variance ratio and the absolute open flow potential variance ratio. Among the influential factors, the length of horizontal well is the most sensitive one to the productivity, followed by fractures' number, half-length of the fracture and the fracture conductivity. It is the same way with the result of productivity influential factors' analysis that the fractured horizontal well productivity is not sensitive to fracture conductivity.

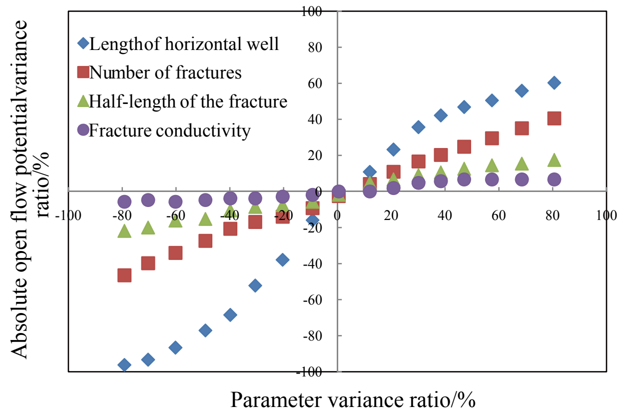

Figure 5
The Sensitivity Analysis of Fractured Horizontal Well Productivity Influential Factors

CONCLUSION

(a) Based on the natural gas non-linearity unsteady seepage theory, the pseudo-pressure pattern and the overlay principle, this paper set up the fractured horizontal well productivity model in the tight sandstone gas reservoir, which takes fracture interferences into consideration.

(b) Combined with the productivity model above, a research has been performed which analyses different parameters' influential degrees to the productivity. According to the relation curves between cumulative gas production and different influential factors, the related optimum values are as follows: The best length of horizontal well is 900 m and the corresponding optimal number of fractures is 6, while the optimal transformation radius, namely the half-length of the fracture is 80 m.

(c) The sensitivity analysis of productivity influential factors has been carried on. Research shows that the length of horizontal well is the most sensitive influential factor to the productivity, followed by fractures' number, half-length of the fracture and the fracture conductivity. For the tight sandstone gas reservoir, the effect of fracture conductivity to the fractured horizontal well productivity is not obvious.

REFERENCES

[1] Zeng, F. H., Guo, J. C., & He, S. G. (2012). Optimization of fracture parameters of fractured horizontal wells in tight sandstone gas reservoirs. *Natural Gas Industry*, (11), 54−58.

[2] Zhang, H. Y. (2014). Optimization of tight gas reservoir horizontal well parameters. *Natural Gas and Oil*, (4), 39-42.

[3] Ma, X., Ren, D. F., & Wang, Y. J. (2012). Productivity prediction of fractured horizontal well in tight gas reservoir. *Natural Gas Exploration and Development*, (2), 48-52.

[4] Cao, B. J., Li, X. F., & Jiang, Z. J. (2009). A research on the asymmetric fracture productivity models for fracturing volcanic gas wells. *Natural Gas Industry*, (8), 79-81.

[5] Wang, Y. N., Wu, X. D., & Wang, R. H. (2013). Study on the productivity characteritics-tic for horizontal fracture well in low-permeability gas reservoirs with non-lin-ear seepage. *Drilling & Production Technology*, (2), 69-71.

[6] Ma, X. F., Fan, F. L., & Zhang, S. L. (2005). Fracture parameter optimization of horizontal well fracturing in low permeability gas reservoir. *Natural Gas Industry*, (9), 61-63.

[7] Chen, F. J., Tang, Y., & Liu, S. D. (2012). Study on the optimization of staged fracturing of a horizontal well in a tight gas reservoir with low permeability. *Special Oil & Gas Reservoirs*, (6), 85-87.

[8] Zhang, Q. W., Xin, J., & Li, Y. M. (2014). Study on horizontal well fracturing fracture parameters optimization of Sulige gas field. *Petroleum Geology and Engineering*, (2), 116-119.

[9] Zeng, F. H., Guo, J. C., & Xu, Y. B. (2007). Factors affecting production capacity of fractured horizontal wells. *Petroleum Exploration and Development*, (4), 474-477.

