A NEW MODEL CONSIDERING NONLINEAR FLOW IN THE LOW-PERMEABILITY FRACTURED GAS RESERVOIR

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Abstract: Low permeability reservoirs accounted for a large proportion of reservoirs discovered in the world, and take an important position in the natural gas producing. Low permeability fractured gas reservoir features very low matrix permeability, with natural fractures closing soon in developing procedure, so the matrix and fracture flow appear the features of nonlinear flow (Fig. 1). Therefore it is difficult to be accurately described by traditional fractured model that based on linear flow rules.

On the foundation of nonlinear flow experiments, this thesis analyzes the applicable conditions of Warren-Root, Kazemi and Thomas model, and takes into account several effects of nonlinear flow in the matrix and fracture flow (low speed nonlinear flow, high speed nonlinear flow, stress sensitivity), thus establishes a newly theoretical model of nonlinear flow in low permeability fractured gas reservoir (eq. 1-6). Case analysis obtained: non-linear gas flow reduces development indicators such as the stable production period, production capacity and the degree of development, limiting the effective development of gas reservoirs (Fig. 2-4), so nonlinear flow should be considered in gas reservoir developing procedure.

The new model considering incluence of nonlinear flow can provide guidance to low permeability fractured gas reservoir development.

Key words: low permeability fractured gas reservoir, nonlinear flow, stable production period, production capacity, new model

Introduction

As a high quality, efficient, clean energy and an important chemical raw material, natural gas become more and more popular around the world. From the perspective of environmental protection and the energy structure optimization, the 21st century will be the century of natural gas. However, gas reservoirs having been discovered in China mostly belong to middle and low permeability reservoirs, and low permeability, extra-low permeability reservoirs accounted for a large proportion, storing a great amount of resources. The flow mechanism Low permeability gas reservoirs and tight gas reservoirs, compared with the conventional gas reservoir, is extremely complex. Gas field development practices and laboratory experiments show that the low permeability fractured gas reservoir has significantly different flow characteristics with high permeability reservoirs, under certain conditions, nonlinear seepage flow of gas, making the flow deviation from the linear equations of motion of Western law. Low permeability fractured gas reservoir is typical of very low matrix permeability, there is pressure gradient; fracture flow with a stress-sensitive and high-speed non-Darcy flow. Describe the fracture line in the current gas reservoir flow model, either the Warren-Root model, Kazemi model and the Thomas and other models are based on Darcy's law, without considering the impact of nonlinear flow, which makes the low permeability gas reservoir model fractured gas reservoir flow is difficult to be accurately described by traditional fractured model. Therefore, it is necessary to establish low permeability fractured gas reservoir linear flow model, to carry out non-linear flow on the low permeability fractured gas reservoir development studies.

1. Low permeability fractured gas reservoir nonlinear flow characteristics

1.1 Low speed nonlinear flow

The late 19th century, deviations from Darcy's law have been found in the low speed groundwater flow in the soil; 20th century has found in water and oil in the soil, sand, porous ceramics and underground reservoirs have deviated from the flow in the Darcy's law. Non-Darcy flow is characterized by pressure gradient, flow rate when the pressure gradient is not increased by the slow non-linear law, the pressure gradient over the starting pressure gradient flow rate before, after a rapid increase by a linear law[2-5] (Figure 1).

1.2 High speed nonlinear flow

It was found through a large number of experiments: When the flow velocity exceeds a certain value, the flow velocity and pressure gradient will destroy the linear relationship between the experimental curve started to deviate from a straight line: the greater the flow rate of departure from the more (Figure 1). Near the bottom of the wells, even in the whole gas reservoir, the high-speed gas flow, high-speed generation of nonlinear flow or turbulence is inevitable phenomenon. Therefore, for high-speed flow of gas, high-speed in the development process to consider the impact of nonlinear effects is extremely important.

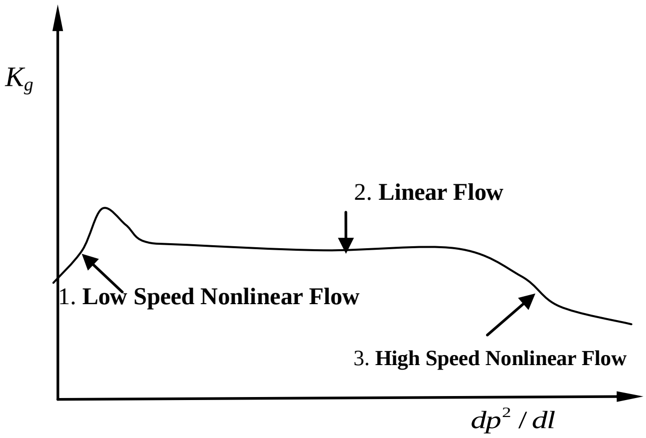

Fig.1 Gas permeability vs. pressure gradient

1.3 Stress sensitivity[8]

In the process of gas depletion due to fluid output, will cause pore pressure changes, causing changes in reservoir rock by the force generated pore deformation, thereby causing the reservoir rock porosity and permeability changes in physical parameters such as That the reservoir stress sensitivity. Fracture permeability and effective stress changes greatly, the stress sensitivity is very strong, and the cracks are the main diversion channel rather than the storage space, so research should focus on the stress sensitivity of permeability stress sensitivity.

2. A new model considering nonlinear flow in the low-permeability fractured gas reservoir

For fractured porous reservoir, can be the fracture system and matrix system in the same space as two separate but linked to the hydrodynamic field of the complex. Fracture system is characterized by low porosity, high permeability, high conductivity pressure capability, it often cracks as the main channel flow. Matrix system is characterized by large porosity, low permeability, low mobility, so often as the matrix "source" and "sink" of items. According to conservation of mass, the flow between the matrix, if ignored, that is considered as a single percolation model with two holes, the matrix system and the fracture system in the mass conservation equation is:

Fracture Flow Equations

Gas.

$$\nabla\cdot\left(\frac{\rho_g\vec{K}_f K_{rg}}{\mu_g B_g}\nabla\Phi_{gf}+\rho_g R_{sw}\frac{\vec{K}_f K_{rw}}{B_w\mu_w}\nabla\Phi_{wf}\right)-q_g-\tau_{gmf}=\frac{\partial}{\partial t}\left(\phi_f\rho_g\left(\frac{S_{gf}}{B_g}+\frac{R_{sw}S_{wf}}{B_w}\right)\right)_f \tag{1}$$

Water.

$$\nabla\cdot\left(\frac{\rho_w\vec{K}_f K_{rw}}{\mu_w B_w}\nabla\Phi_{wf}\right)-q_w-\tau_{wmf}=\frac{\partial}{\partial t}\left(\frac{\phi_f\rho_w S_{wf}}{B_w}\right)_f \tag{2}$$

Matrix/Fracture Flow Equations

$$\tau_{lmf}=\sigma\frac{\rho_l\vec{K}_m K_{rl}}{\mu_l B_l}\nabla\left(P_{lf}-P_{lm}\right),\qquad (l=g,w) \tag{3}$$

Low Speed NonLinear Flow Equation

$$k_m=k_{mi}\beta_\lambda,\qquad \left(\left|\frac{\mathrm{d}p}{\mathrm{d}l}\right|\geq\lambda_\alpha\right) \tag{4}$$

Stress Sensitivity Flow Equation

$$\vec{K}_f=\vec{K}_{fi}\alpha_g \tag{5}$$

High Speed NonLinear Flow Equation

$$\vec{K}_f=\vec{K}_{fi}\xi_l \tag{6}$$

Finite difference method will be considered non-linear flow in low permeability fractured gas reservoir flow of new fully implicit discrete model[9-10], and then using Newton-Raphson iteration method for solving discretized nonlinear equations. Based software engineering, in the Windows environment, the preparation of the low permeability fractured gas reservoir linear flow simulation program.

3. Case Study

A low permeability fractured gas reservoir Center for the study of a well, prepared by the present model-based software for linear flow on the low permeability fractured gas reservoir development impact. Simulation parameter values shown in Table 1 to 4, the simulation results shown in Figure 2 to 4.

Table 1 The model data

Parameters	Value	Parameters	Value
grid	15×15×5	B_w	1.04
grid step(m)	100×100×5	C_w（MPa^{-1})	4.3×10^{-4}
depth(m)	6638	γ_g	0.609
γ_w	1	p_r（MPa)	113.2
μ_w (mPa.s)	0.33	T_r（^oC)	168.6
K_{mx}（mD）	0.3	K_{fx}（mD）	100
K_{my}（mD）	0.3	K_{fy}（mD）	100
K_{mz}（mD）	0.1	K_{fz}（mD）	1
Φ_m（%）	5.5	Φ_f（%）	1.3
C_m（MPa^{-1})	4.35×10^{-4}	C_f（MPa^{-1})	1×10^{-3}
λ_m（MPa/m）	1×10^{-3}	α_f（MPa^{-1})	2×10^{-3}

Table 2 The gas-water relative permeability and capillary pressure data in fracture

S_{wf}	K_{rwf}	K_{rgf}	P_{cgwf}/MPa
0	0	1	0.00
1	1	0	0.00

Table 3 The gas-water relative permeability and capillary pressure data in matrix

Swm	Krwm	Krgm	Pcgwm/MPa
0.000	0.000	1.000	0.200
0.320	0.000	1.000	0.187
0.400	0.011	0.605	0.093
0.450	0.017	0.413	0.050
0.500	0.025	0.269	0.037
0.550	0.039	0.173	0.028
0.600	0.050	0.106	0.022
0.650	0.077	0.067	0.017
0.700	0.121	0.038	0.015
0.750	0.193	0.019	0.013
0.860	0.297	0.000	0.010
1.000	1.000	0.000	0.001

Table 4 gas PVT data

p(MPa)	μ_g(mPa.s)	Z	C_g(MPa^{-1})
112.90	0.03945	1.7177	0.00432
108.86	0.03813	1.6563	0.00457
105.11	0.03681	1.6139	0.00494
98.59	0.03549	1.5262	0.00586
92.36	0.03417	1.4388	0.00697
86.29	0.03264	1.3501	0.00867
80.47	0.03109	1.2625	0.01140
75.08	0.02953	1.1796	0.01559
70.22	0.02798	1.1039	0.02268
66.17	0.02639	1.0406	0.03586
63.49	0.02468	0.9985	0.06448
62.26	0.01431	0.9793	0.06600

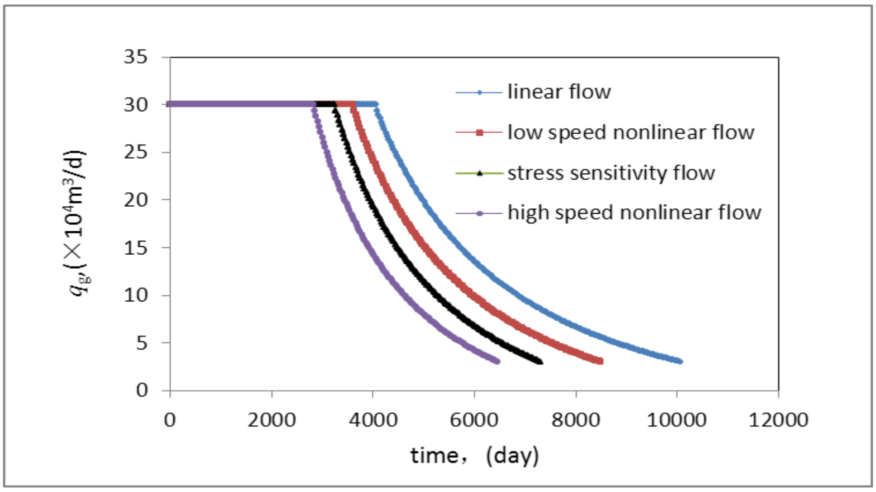

Fig.2 comparision of gas-well plateau duration

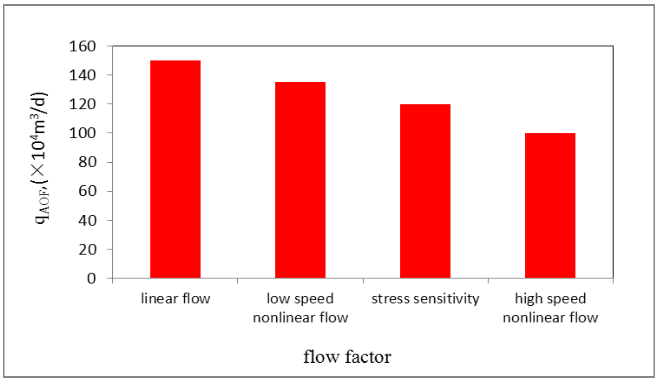

Fig.3 comparision of gas-well Production index

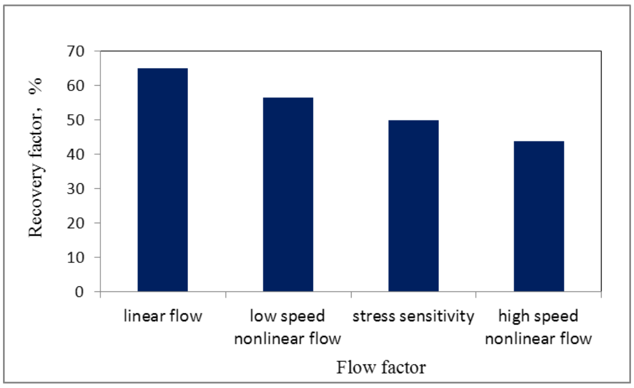

Fig.4 comparision of gas-well recovery factor

By case analysis (Fig. 2 to 4) obtained: non-linear gas flow reduces the stable production period, production capacity and the degree of development of indicators of recovery, limiting the effective development of gas reservoirs. Reduce the nonlinear flow channeling between matrix crack pressure, in the stage production quotas, considering nonlinear flow of the stable flow of less than linear; in fixed bottomhole pressure stage, consideration of nonlinear seepage gas production is less than the linear flow of production.

4.Conclusions

(1) The establishment of new models with the consideration of nonlinear flow in low permeability fractured gas reservoir flow, and development of software to solve the model.

(2) Simulation results show that the nonlinear flow reduces the stable production of gas reservoir, production capacity and the degree of development of indicators of recovery, limit the effective development of gas, so to be considered in the development process of non-linear flow.

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