Fuel 143 (2015) 543–546

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Numerical simulation of hydraulic fracturing coalbed methane reservoir with independent fracture grid

Zhang Jingchen [a,b,*], Bian Xiaobing [c]

[a] Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom
[b] MOE Key Laboratory of Petroleum Engineering, China University of Petroleum (Beijing), Beijing 102249, China
[c] Petroleum Engineering Technology Research Institute of Sinopec, Beijing 100101, China

HIGHLIGHTS

- A two-phase, three-dimensional model of single fracturing coalbed methane well is developed.
- IMPES method and independent fracture grid are applied to the numerical solution.
- Independent fracture grid method is compared with equivalent percolation resistance method.

ARTICLE INFO

Article history:
Received 13 July 2014
Received in revised form 17 November 2014
Accepted 20 November 2014
Available online 11 December 2014

Keywords:
Hydraulic fracturing
Coalbed methane
IMPES method
Independent fracture grid

ABSTRACT

Hydraulic fracturing stimulation technology is an effective method for increasing coalbed methane production, especially for coal seam with low permeability, low reservoir pressure and low gas saturation. Normally, fracture is simulated according to the law of equivalent percolation resistance, leading to the limit that fracture is several hundred times enlarged meanwhile the permeability is decreased, with wellbore located in the enlarged fracture, more fluids will produce through high conductive fracture path into wellbore. Based on theories and methods from oil–gas geology and mechanics of flow through porous media, this paper presents a two-phase, 3D flow and hydraulic fracturing model of dual-porosity media. A finite difference numerical model with independent fracture grid has been developed and applied successfully to a coalbed methane reservoir. Comparison results show that independent fracture grid is more effective than equivalent percolation resistance method in production fitting. Actual gas production data is consistent with results calculated by the new model, while prediction from equivalent percolation resistance is higher.

1. Introduction

Hydraulic fracturing stimulation technology is the primary means in enhancing production of coalbed methane wells. More than 90% of coal seam is improved through hydraulic fracturing among 14,000 multi-port coalbed methane wells in United States. There may be a number of far extended cracks in the internal of fractured coal seams. This can result in the pressure drop in a large area around borehole, thus gas desorption surface area of coal seam enlarged which guarantees the discharge of coalbed methane rapidly and sustainably. Coalbed methane production of fractured coal seams is 5–20 times of pre-fracturing condition [1–3].

Many scholars have conducted a lot of research on numerical simulation. Boyer et al. [4] conducted Laboratory and field tests to establish criteria for containment of an induced hydraulic fracture. Holditch et al. [5] utilized hydraulic fracturing treatments to optimize recovery from most of the wells that drilled into deep coal seams. Wright et al. [6] summarized a few enhancements for coal seam fracturing technology, as well as the present limitations and the necessary advancements required for superior coal seam fracture performance in future. Zuber et al. [7] analyzed hydraulic fracturing design on the impact of ECBM (Enhanced Coal Bed Methane Recovery). McDaniel [8] firstly applied hydraulic fracturing techniques to the stimulation work of coalbed methane wells. Jinzhou et al. [9] described hydraulic fracturing technique for coalbed methane gas reservoirs with low permeability and also developed a set of optimal design software for low permeability hydraulic fracturing coalbed gas reservoirs. Yanli and Wang [10] analyzed characteristics of pressure of coal seam fracturing and

* Corresponding author at: Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom. Tel.: +44 (0)1314513721.
E-mail address: jingchen120@126.com (J. Zhang).

http://dx.doi.org/10.1016/j.fuel.2014.11.070
0016-2361/

Nomenclature

v_g	gas area velocity of cleat (cm/s)	p_{fw}	water pressure of cleat, 10^{-1} MPa
B_g	gas volume factor of cleat	s_w	water saturation of cleat, decimal
q_{vg}	gas production items (cm^3/(cm^3 s))	$\overline{V}_m$	average concentration of gas in matrix element (cm^3/cm^3)
D	depth away from the datum (cm)	V_E	gas concentration in the surface of matrix element (cm^3/cm^3)
q_{mfg}	gas diffusion rate of gas cross flow from matrix to cleat (cm^3/(cm^3 s))	τ	desorption time of coalbed methane (s)
ϕ_f	porosity of cleat, decimal	μ_{mg}	gas viscosity of matrix element (MPa s)
s_g	gas saturation of cleat, decimal	F_G	geometry-related factor
∇	Hamilton operator	p_{fg}^0	initial reservoir pressure of coalbed methane, a given function
k_f	permeability of cleat (μm^2)	s_g^0	initial gas saturation of coalbed methane, a given function
k_{rg}	gas relative permeability of cleat, decimal	r_w	radius of wellbore
p_{fg}	gas pressure of cleat, 10^{-1} MPa	k_{fx}, k_{fy}	permeability in different directions of cleat system
μ_g	gas viscosity of cleat (MPa s)	Γ	outer boundary of coalbed methane, n represents external normal direction of outer boundary
ρ_g	gas density of cleat (g/cm^3)	$p_e(x, y, z, t)$	known function related to pressure
k_{rw}	water relative permeability of cleat, decimal		
B_w	water volume factor of cleat		
μ_w	water viscosity of cleat (MPa s)		
ρ_w	water density of cleat (g/cm^3)		

the relationship between depth and break pressure gradient. Zhang and Wang [11] introduced dynamic (potential) testing technique used for determination of fracturing azimuth, length and other parameters of coal seam. Zhiliang and Meng [12] used acoustic detection system to carry out seismic tomography tests before and after fracturing respectively in order to determine fracturing effect. Clarkson [13] provided a new workflows and analytical approaches for analyzing single and multi-phase flow of CBM (Coal Bed Methane) from vertical, hydraulically-fractured wells and horizontal wells.

In terms of numerical treatment of hydraulic fracturing, if the fracture is considered as a separate row of grid, the volume of mesh block is extremely small due to the small actual width of the mesh block that fracture lies in. Internal formation near fracture need to expand gradually to ensure the convergence and stability of difference schemes' solution, however, this will undoubtedly increase time and memory share of computer. Normally, fracture is simulated according to the law of equivalent percolation resistance, leading to the limit that fracture is several hundred times enlarged meanwhile permeability is decreased, with wellbore located in the enlarged fracture, more fluids will produce through the high conductive fracture path into wellbore [14,15]. Hence independent fracture system is developed.

Chen, Zhang and Wen [16–18] developed reservoir numerical simulators for optimizing regular well pattern by integral fracturing technique. Two separate systems, fracture system and reservoir system, are coupled with equivalent pressure and flow rate between the boundary of fracture and reservoir. For five spot well pattern and nine spot well pattern, oilfield development program could be economically optimized considering different well spacing, fracture direction, fracture parameters and producing pressure drawdown. By adding limited independent fracture grids, this method does not increase the amount of computations.

Although many scholars had studied the exploitation of CBM as well as the impact of hydraulic fracturing on CBM, few had taken hydraulic fracturing into consideration in three dimensional and two phase coalbed methane reservoir. In the former research [14], the author presents a two-phase, 3D flow and hydraulic fracturing model of dual-porosity media based on the theories of oil–gas geology and mechanics of flow through porous media. A computer program based on the law of equivalent percolation resistance has been coded. Well test data from one western China basin, which include all parameters needed in simulation work, prove that the model established in this paper is reasonable and feasible. In this paper, method of equivalent percolation resistance and independent fracture grid are compared with these data.

2. Mathematical model of coalbed methane reservoir

2.1. Gas seepage equation in the cleat system

According to continuity equation, Darcy's law, general form of gas seepage equation is shown as follows:

$$\nabla \cdot \left[\frac{\rho_g k_f k_{rg}}{\mu_g}(\nabla(p_{fg} - \rho_g g D)) + D_f \nabla\left(\frac{s_g}{B_g}\right)\right] + q_{vg} + q_{mfg} = \frac{\partial}{\partial t}\left(\frac{\phi_f s_g}{B_g}\right) \tag{1}$$

2.2. Water seepage equation in the cleat system

Similarly, water seepage equation in the cleat system can be described as follows:

$$\nabla \cdot \left[\frac{k_f k_{rw}}{B_w \mu_w}(\nabla(p_{fw} - \rho_w g D)\right] + q_{vw} = \frac{\partial}{\partial t}\left(\frac{\phi_f s_w}{B_w}\right) \tag{2}$$

2.3. State equation in the cleat system

Eqs. (1) and (2) are the second-order nonlinear partial differential equations which contain four unkowns: p_{fg}, s_g, p_{fw}, s_w. At the same time, p_{fg}, s_g, p_{fw}, s_w satisfy state equation as follows:

$$s_g + s_w = 1 \tag{3}$$

$$p_{cgw}(s_g) = p_{fg} - p_{fw} \tag{4}$$

The $p_{cgw}(s_g)$ in Eq. (4) is called capillary pressure function, which is a given function.

2.4. Gas desorption and transportation equation in the cleat system

Considering the steady-state case, average gas concentration in the matrix is subject to desorption of adsorption gas, thus gas